

(NASA-L2-100107) ALIEN IONOSPHERE LIMITS TEST
FOR SHUTTLE CRAFTS FINAL REPORT, APR. - MAY
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NASA
**RL10 IGNITION LIMITS TEST
FOR SHUTTLE CENTAUR**

FINAL REPORT

CONTRACT NAS3-22902

**Prepared for
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**UNITED
TECHNOLOGIES
PRATT & WHITNEY**

FOREWORD

This report presents the results of the ignition limits testing of the RL10 engine for the Shuttle/Centaur program. The testing was conducted by Pratt & Whitney, Government Products Division (P&W/GPD) of the United Technologies Corporation (UTC) for the National Aeronautics and Space Administration Lewis Research Center (NASA/LeRC) under contract NAS3-22902.

This testing was conducted during the period of March through May, 1986. The testing effort was conducted under the direction of LeRC Space Flight Systems Directorate with Mr. James A. Burkhart as Contracting Officer Representative. The effort at P&W/GPD was carried out under the direction of Mr. Carl Ring, Assistant Project Engineer, and Mr. Tom Vogel, Senior Test Engineer.

SUMMARY

During routine development testing of the RL10A-3-3B engine a potential no-ignition condition was encountered when operating at certain propellant inlet conditions within the Shuttle Centaur "G" operating region. This report discusses the conditions, the resulting investigative program and methods to correct the potential problem. The Shuttle Centaur program was cancelled prior to completion of this effort.

Although the RL10 engine in the Atlas Centaur vehicle is required by specification to operate over a wide range of propellant inlet conditions. The vehicle actually operates over a narrow range of conditions. This factor, combined with configuration differences between Atlas Centaur (or Titan Centaur) and the Shuttle Centaur RL10 engines, indicates the ignition problem does not exist for these vehicles. As a precautionary measure the vehicle manufacturer has been requested to coordinate with Pratt & Whitney any anticipated changes in propellant inlet conditions from the current narrow range. An engineering change will be proposed for future RL10 deliveries to provide more consistent propellant flow to the igniter. This will permit operation of the engine throughout the wide range specification inlet conditions if desired.

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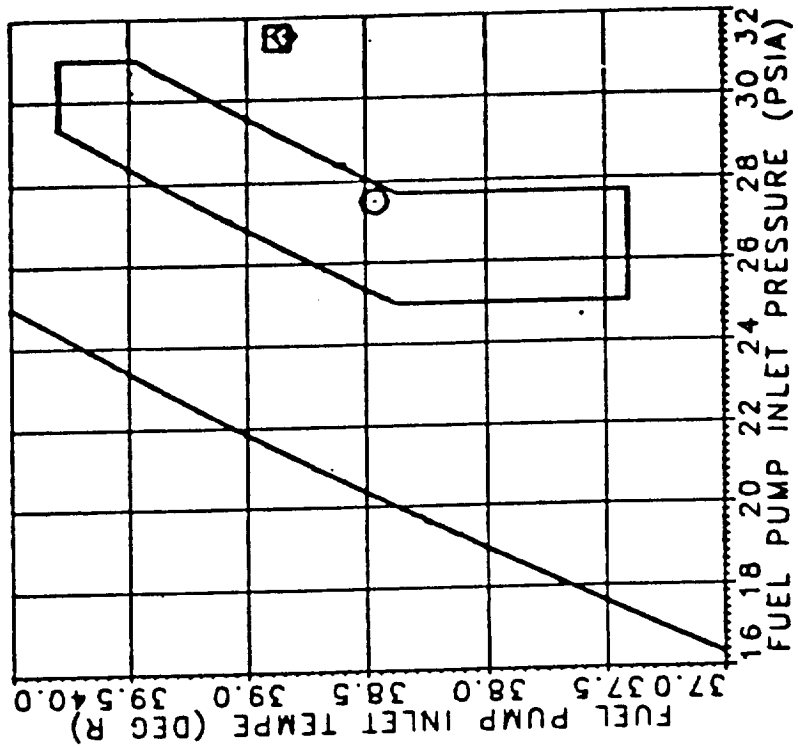
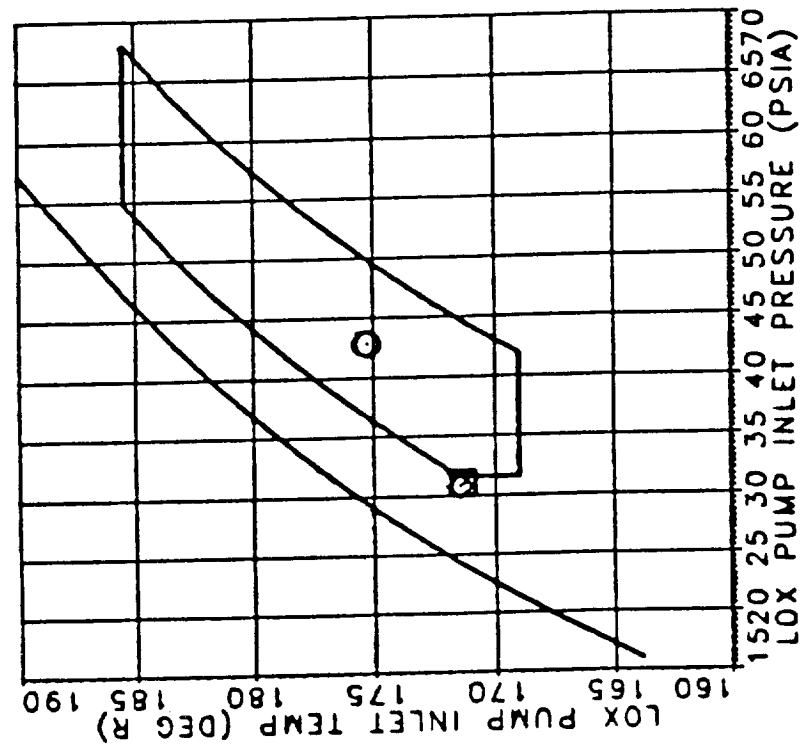
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SECTION 1.0 BACKGROUND

The Shuttle/Centaur ignition investigation was originally prompted by three no-lights during Shuttle/Centaur RL10A-3-3B testing. Figure 1 shows the engines and conditions at which these no-lights occurred. To investigate these occurrences, an ignition investigation was run on engine XR105-3 (runs 35-41). This study concluded that the igniter mixture ratio needed to be increased to ensure that the igniter was within the ignition range. Also, the need for conducting tests with evacuated cooldown valves was demonstrated. (Note: During Centaur operation the RL10 cooldown valves discharge to high altitude vacuum during the cooldown. This process is simulated during ground test by "evacuating" the cooldown valve discharge system with a steam ejector. This process is not routinely used due to the potential for contaminating the engine with water from the steam system and also due to steam consumption. It is utilized when required for special tests). Start transients with evacuated cooldown valves were shown to have a lower unlit chamber pressure, and slightly higher oxidizer/fuel (O/F) mixture ratio, than those with non-evacuated cooldown valves. Hence, it is possible to be within the ignition region with non-evacuated cooldown valves and out of it with evacuated valves. Appendix C gives more details of the XR105-3 testing along with a summary of the runs made. This test series was concluded prematurely by water contamination of the engine, however, the need for further testing was apparent. Therefore, engine XR103-3 was run to investigate igniter oxidizer plumbing schemes and increased igniter oxidizer flow area to increase igniter flow. In the meantime, a hydrogen leakage path was discovered in the igniter. This leakage may add anywhere between 30 percent and 180 percent of the nominal hydrogen orifice area to the total flow area. The leakage areas in the igniters run in XR103-3 were measured so that the actual H_2 flow could be determined.

- THREE NO-LIGHTS ENCOUNTERED WHILE TESTING RL10A-3-3B ENGINES WITHIN THE SHUTTLE/CENTAUR "G" START BOXES
- ALL THREE WERE RELIGHT ATTEMPTS
- EXPERIENCED MANY LIGHTS AT SAME CONDITIONS

1—○—XR103-2 RUN 14.01
 2—□—XR101-4A RUN 100.01
 3—○—XR101-4A RUN 110.01



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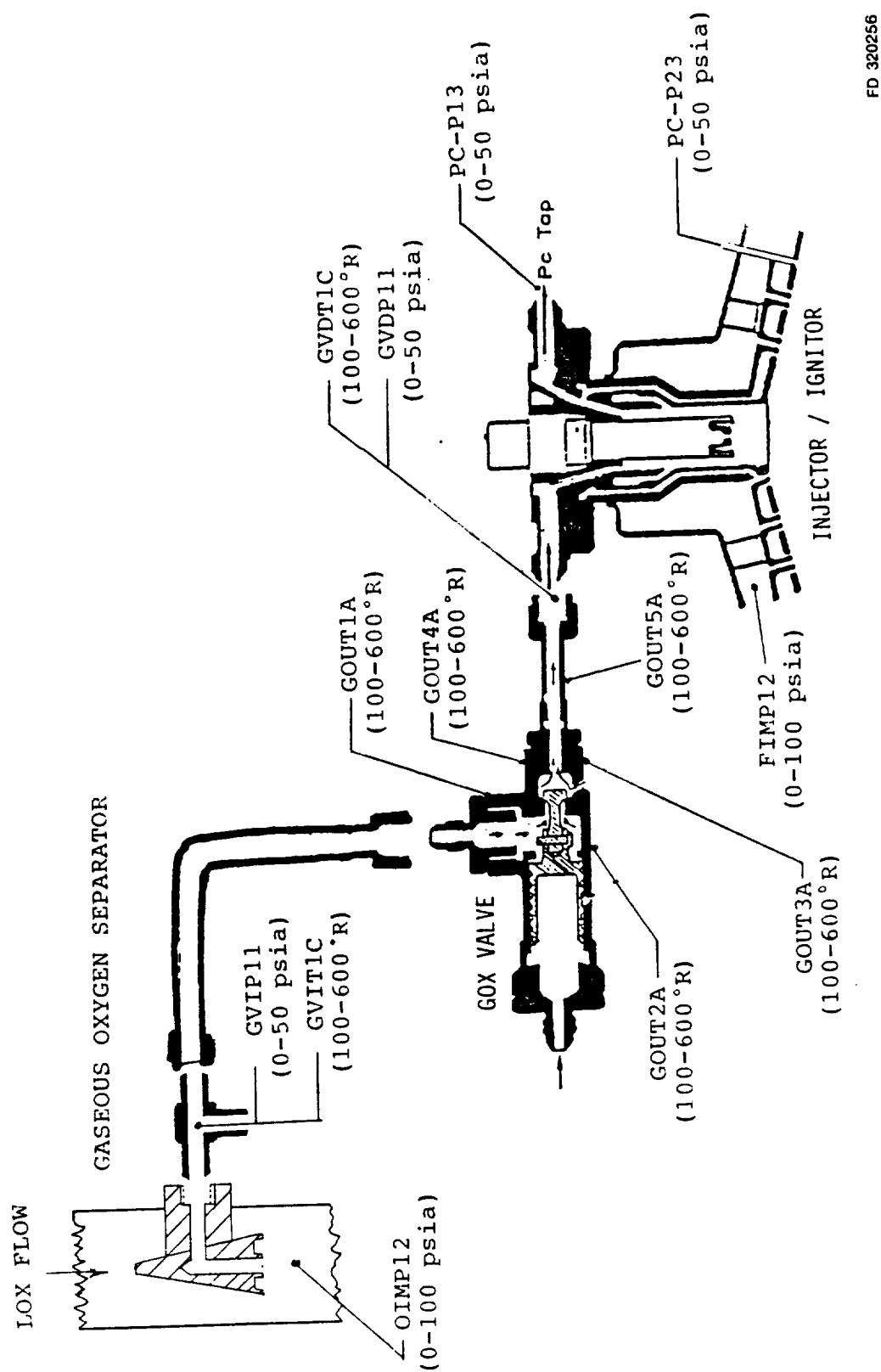
Figure 1. Engine Conditions at Which No-Lights Occurred

SECTION 2.0

HARDWARE AND TEST PROCEDURE

Special instrumentation was provided to monitor oxidizer pressures and temperatures in the GOX valve plumbing and igniter oxidizer supply lines, as shown in Figure 2. The igniter supply pressure and temperature were used to calculate igniter oxidizer flow. Appendix B outlines the methods used for calculating both chamber propellant flows and igniter flows. Figures 3 and 4 show the igniter/injector geometry and indicate the critical fuel metering holes and the oxidizer orifices. In addition, the location of the leakage gap between the injector sleeve and igniter is pointed out. This leakage can range anywhere from 30 percent to 180 percent of the nominal fuel metering hole area based upon current blueprint tolerances.

The general procedure used for most of the runs was to delay arming of the igniter until 0.2 second after the start signal. This was done to avoid ignition during the short term transient fuel surge which occurs after the main fuel shutoff valve opens. It was desired to investigate ignition characteristics during the stabilized fuel flow period after the surge. These characteristics can be seen in Figure 5. On two tests (47 and 53), the igniter was not armed until 0.6 second after start; this was done to verify that the stabilized flow remained ignitable. Delaying of the igniter was done for testing purposes only and is not recommended for normal engine operation. The runs were terminated after 0.6 to 0.7 second for stand safety considerations.



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Figure 2. Igniter Study — Special Instrumentation

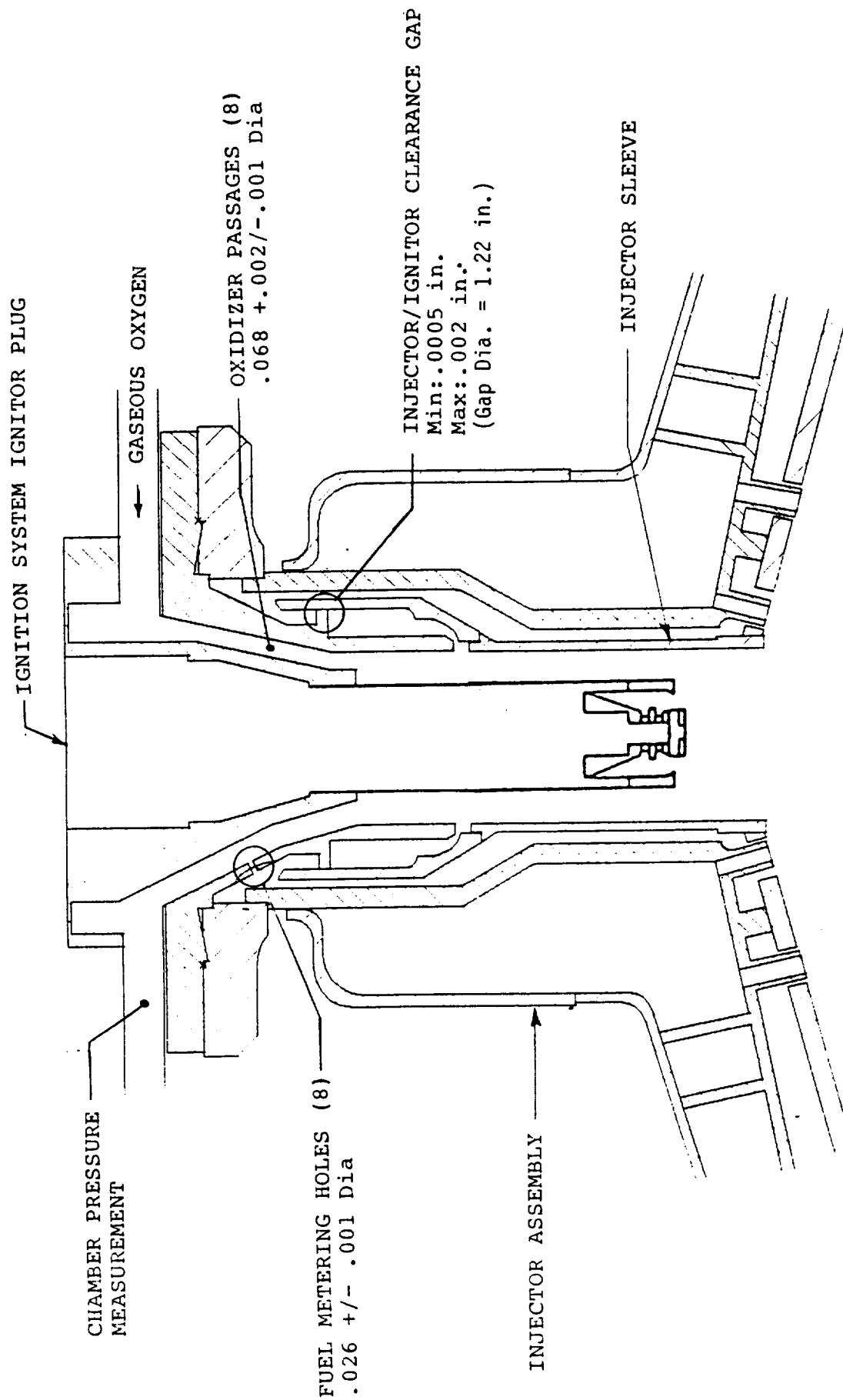
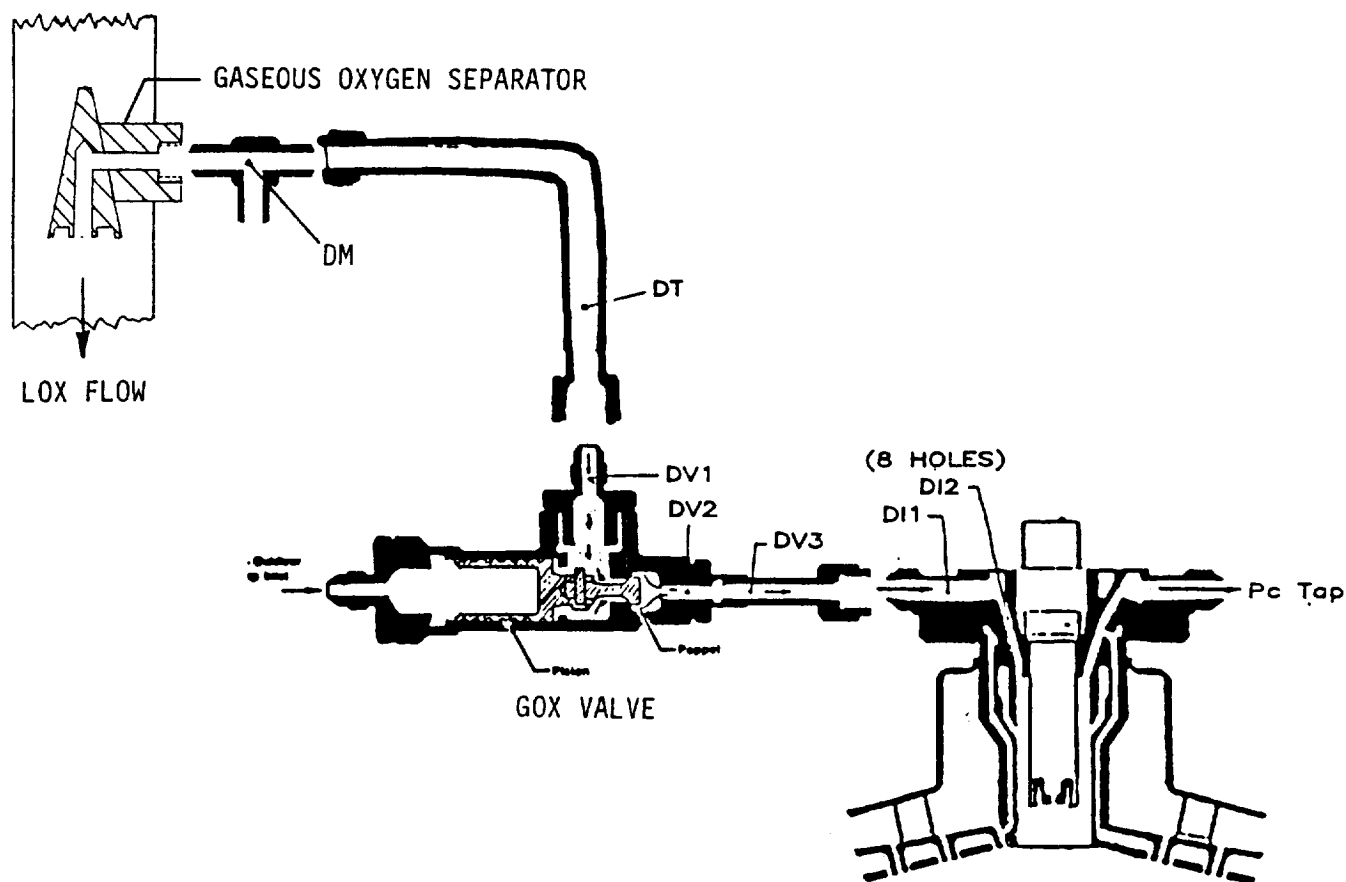


Figure 3. Injector/Igniter Fuel and Oxidizer Flow Areas



CONFIGURATIONS TESTED:

B/M - B/M IGNITOR, VARIOUS SUPPLY SYSTEM SIZES
MOD B - B/M SUPPLY SYSTEM WITH LARGE IGNITOR AREA
MOD C - LARGE SUPPLY SYSTEM WITH LARGE IGNITOR AREA

CONFIG	IGN*	RUNS	DM	DT [†]	DV1	DV2	DV3	D11	D12
B/M	BMT001	29 - 38	.145	#4	.145	.172	.188	.172	.068
MOD B	KE764	39 - 42	.145	#4	.145	.172	.188	.185	.082
MOD C	KE764	43 - 47	.188	#5	.256	.188	.188	.185	.082
B/M	BMT003	48, 49	.172	#4	.172	.172	.188	-	.068
B/M	BMT003	50	.188	#5	.256	.188	.188	-	.068
B/M	BMT003	51	.188	#4	.172	.172	.188	.185	.068
B/M	BMT003	52, 53	.172	#4	.172	.172	.188	.185	.068

*BMT001 - B/M IGNITOR WITH H₂ LEAKAGE AREA = .0013 sq in.

BMT003 - B/M IGNITOR WITH H₂ LEAKAGE AREA = .0031 sq in.

KE764 - MODIFIED IGNITOR WITH H₂ LEAKAGE AREA = .0019 sq in.

[†]#4 TUBING = 4/16 Dia. & #5 TUBING = 5/16 Dia.

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Figure 4. Igniter Oxidizer Supply System Dimensional Summary

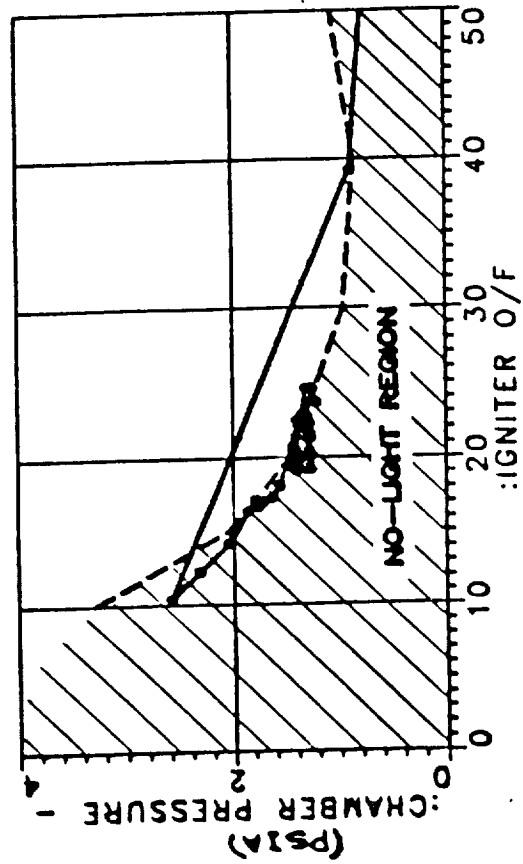
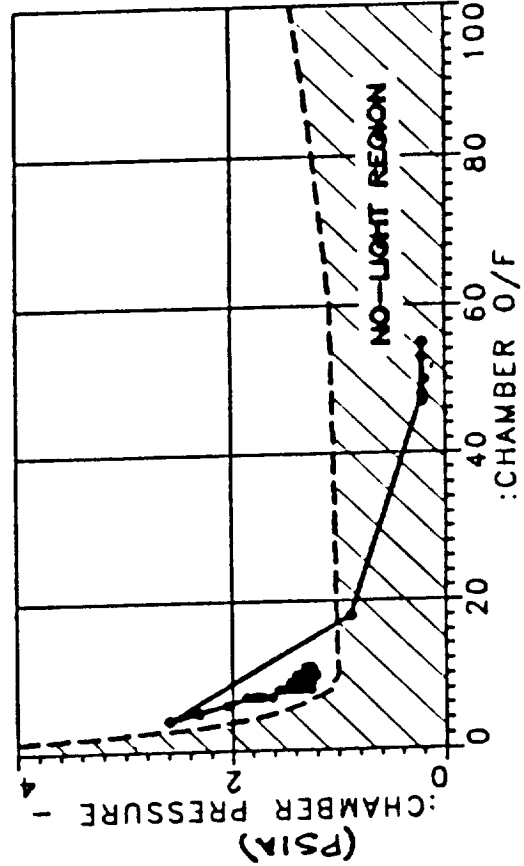
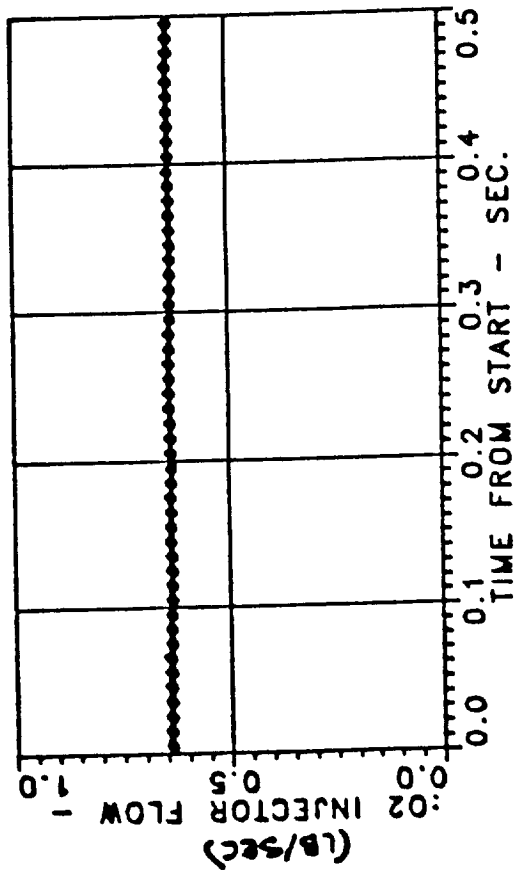
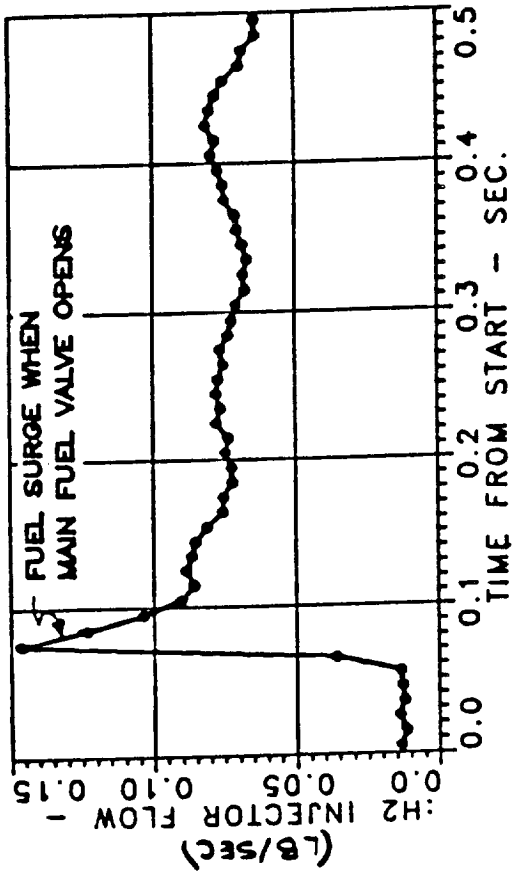


Figure 5. Igniter Delayed 0.2 Second to Get Past the Fuel Surge

SECTION 3.0 RESULTS

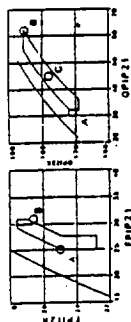
Table 1 summarizes all the runs made in this ignition investigation. The runs are grouped by GOX valve plumbing/igniter configuration. The first group, runs 29 through 38, have a B/M igniter (BMT001) and GOX valve plumbing. The second group, "MOD-B," runs 39 to 42, had the large oxidizer area igniter (0.082 dia holes) but retained the B/M GOX valve plumbing. The third group, "MOD-C," had both the large area igniter and large area plumbing. The remainder of the runs, 48 through 53, had the second B/M igniter (BMT003), however, note that runs 52 and 53 were run in Atlas/Centaur configuration. As indicated in Table 1, most of the runs were made at low oxidizer pump inlet pressures and high fuel pump inlet pressures. This was done to obtain low O/F ratios to test that side of the ignition region. At the right side of Table 1 are given the times at which the igniter was armed. Note that in most cases the igniter was armed at 0.2 second, however, in two runs (47 and 53), the igniter was not armed until 0.6 second. Adjacent columns give time from start signal to chamber ignition, number of sparks to light the igniter, and chamber and igniter flows. Appendix A contains plots of chamber pressure vs O/F ratio and O/F ratio vs time for each run.

Runs 36, 39 and 44 provide a direct comparison of the GOX valve/igniter plumbing schemes (see Table 1). All conditions for these runs were the same except for the GOX valve plumbing. Run 36 had the B/M configuration, run 39 had the "MOD-B" configuration, and run 44 the "MOD-C" configuration. All three were run at maximum fuel pump inlet pressure and below minimum LOX inlet pressure (see Table 1). Run 36 took the longest time to light, 0.599 second, with MOD-B, run 39, lighting at 0.438 second and MOD-C, run 44, lighting fastest at 0.362 second. The mixture ratio plots for these runs can be compared in Appendix A, Figures 6A, 9A and 14A. A large mixture ratio difference is not apparent between runs 36 and 39, but run 44 has a noticeably increased mixture ratio. MOD-C, therefore, is desirable for the Shuttle/Centaur configuration.

Figure 6 shows a plot of the existing igniter bucket (because of the shape of the ignitable region, it is often defined as "bucket"). At the time this was developed, the additional H₂ leakage path in the igniter was not considered, so the H₂ flow used to calculate O/F ratio should be corrected. The actual leakage area in the igniter which was tested is unknown, therefore, the actual amount of correction to be made is uncertain. However, it is certain that at least minimum leakage existed, and since this yields a conservative correction, the curve was corrected by this amount (+30 percent of H₂ flow). This corrected bucket is also shown on Figure 6.

Figure 7 shows chamber pressure vs igniter O/F ratio at light-off along with the corrected igniter bucket for most of the runs. The mixture ratios for the data take into account the appropriate hydrogen leakage flows for each of the igniters used. Open symbols denote runs where ignition occurred immediately upon the first spark; these points do not define the limits of the bucket. The shaded symbols, however, ignited some time after sparking commenced; these runs started out in a non-ignitable region and lit when they moved into the ignitable region. Hence, these can be used to define the ignition bucket limits. Notice the good agreement between the corrected ignition bucket and the right side of the shaded data points in defining the ignition limit.

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* Runs 52 and 53 are Atlas/Contour configuration with Tyler Blanket

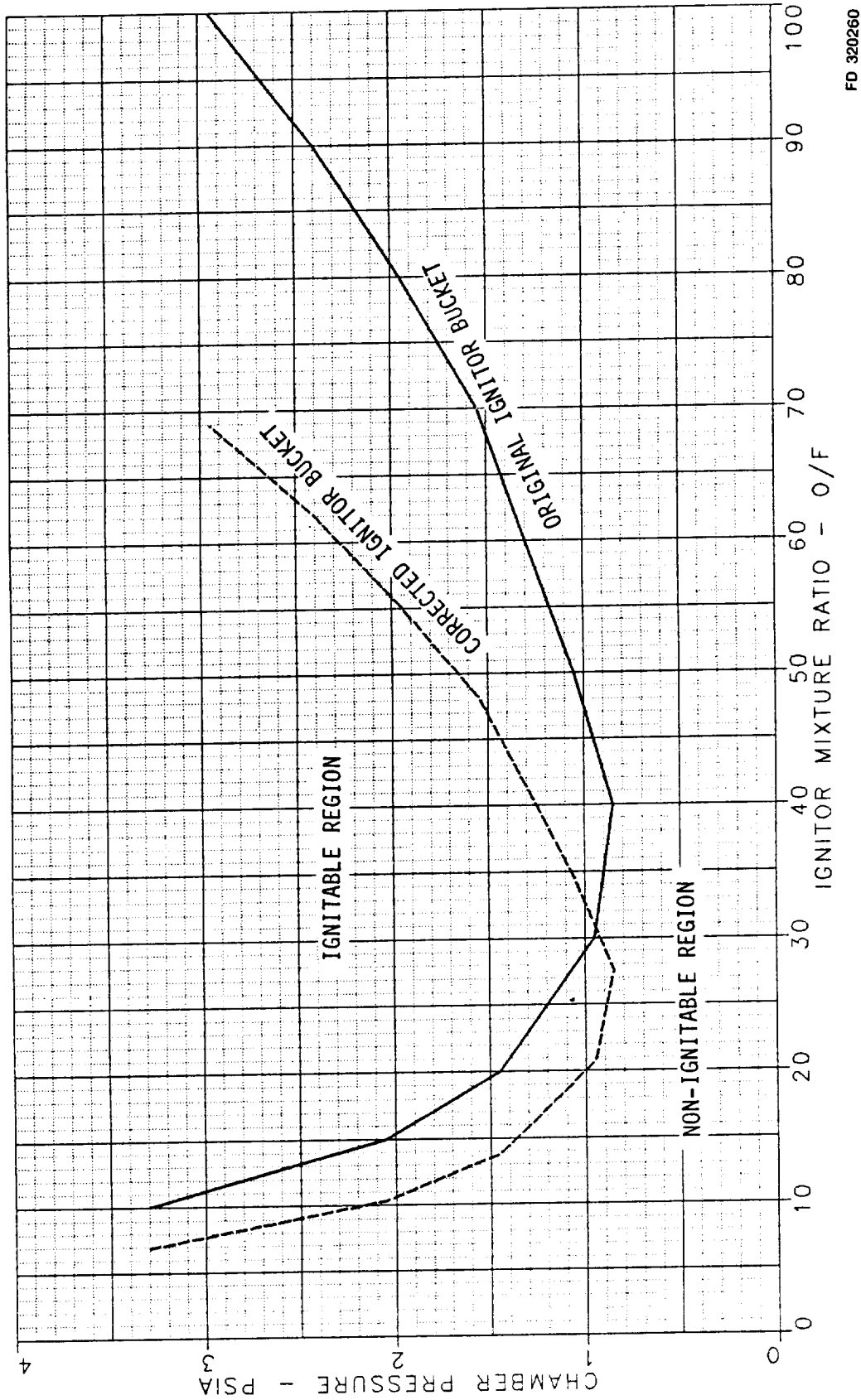
86 line is 4/16 tubing. If 5 line is 5/16 tubing
() predicted value =
e.g. 41.67 have 5V(11) and 5V(11) reversed in data

() predicted value
e.g. 41.47 have GV(PI) and GV(PI) reversed in data (corrected on this sheet)

NOTES:

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042200
040200

1——RL10 IGNITER IGNITION BUCKET FIT ST
2-----RL10 IGNITER BUCKET— MIN LEAK FIT ST



FD 320260

Figure 6. Igniter Bucket Corrected for Minimum H_2 Leakage



Figure 7. Chamber Pressure and O/F Ratio at Ignition

Referring to Table 1, it is seen that in most cases the igniter lit on the first spark and the chamber lit some time later. This phenomenon is referred to as igniter "torching." In many cases the chamber lit between sparks and in run 37, the chamber actually lit at 0.750 second while the igniter was disarmed at 0.700 second. This torching phenomenon is clearly shown by O-graph data. The O-graph trace of chamber pressure (P_c) for run 41 is shown in Figure 8. A small jump in P_c occurs at the first spark indicating that the igniter has lit. The igniter then torches until the chamber lights, indicated by the large jump in P_c . Note that the chamber lights before the second spark. In other runs, the igniter torches for many sparks before the chamber lit. The reason that the igniter can torch without chamber ignition, even though the chamber is within its ignition bucket, may be explained by Figure 9. The igniter torches up near the fuel and oxidizer metering holes. Leakage hydrogen mixes with the combustion products nearer the tip of the igniter and dilutes the gases before entering the chamber. Ignition does not occur until sufficient energy is present in the combustion products.

Hydrogen leakage in the igniter can be significant and can adversely affect the igniter O/F mixture ratio to the point of delaying ignition significantly. However, indications are that unlit engines tend to move with time toward favorable ignition conditions so that ignition will occur in most all cases, although some delay may occur. To avoid the possibility of excessive hydrogen leakage, a leakage control scheme should be implemented. The leakage should not be eliminated entirely, as it has always existed and igniter performance and durability has historically been good, but should be held to the minimum level that currently exists. One possible scheme to do this is shown in Figure 10. This piston ring arrangement would provide a positive seal between the igniter and the injector sleeve and may contain slots for controlled leakage. This arrangement is a concept only and no detailed design has been performed at this point.

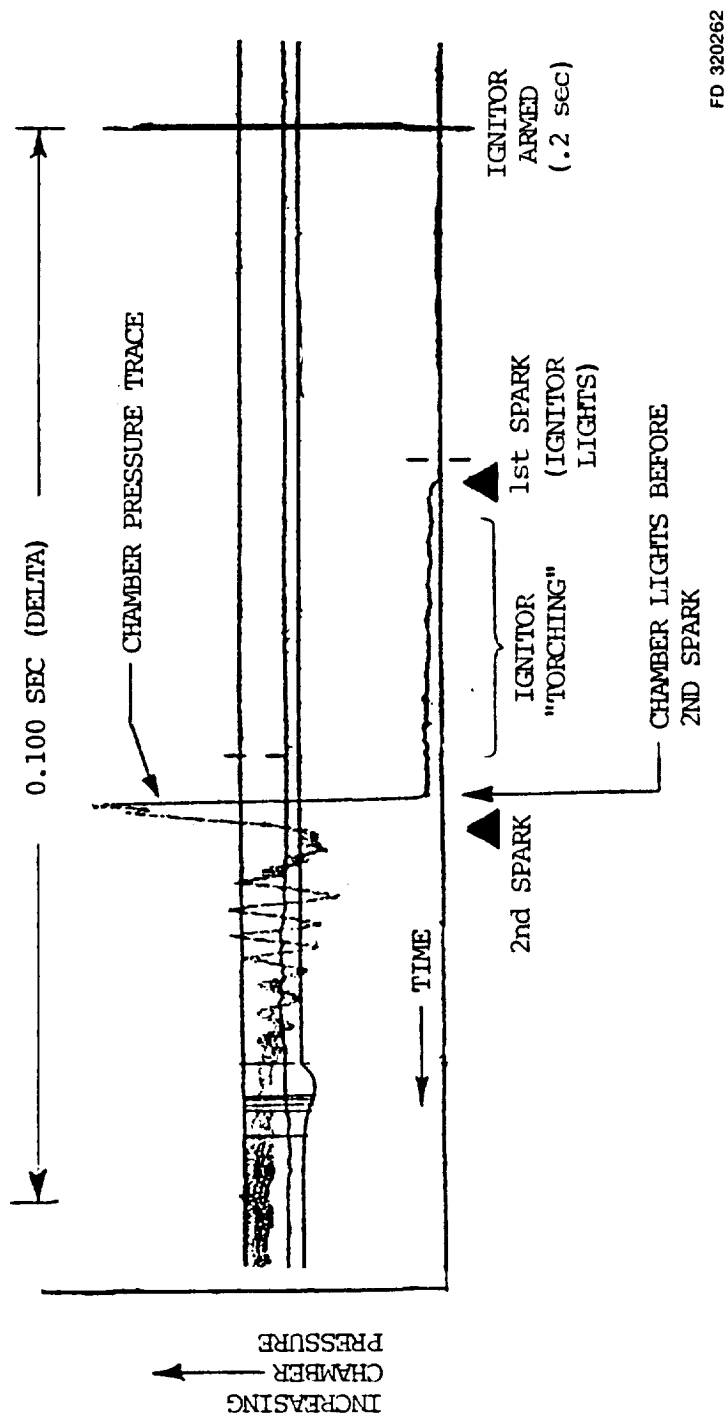
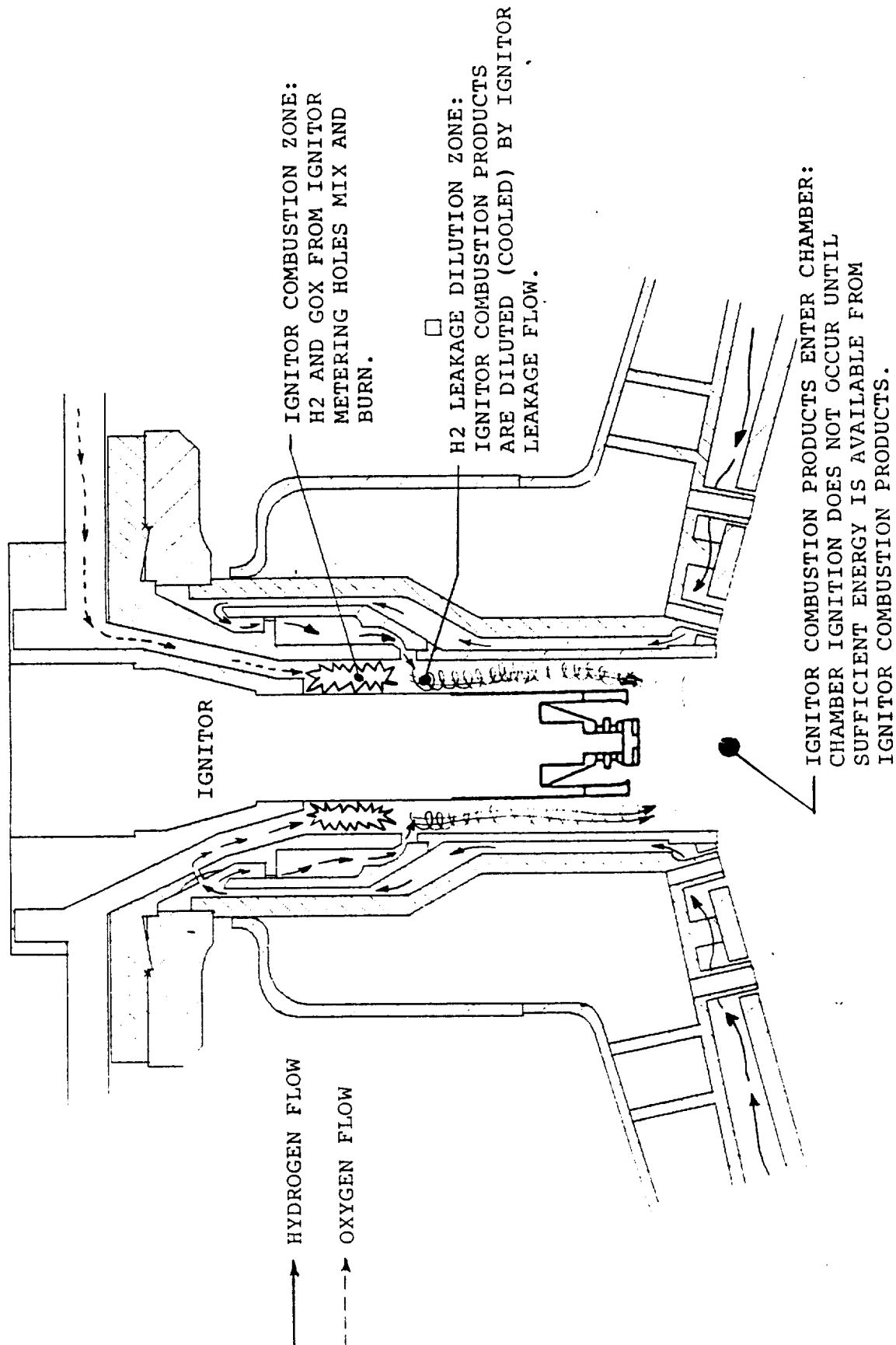
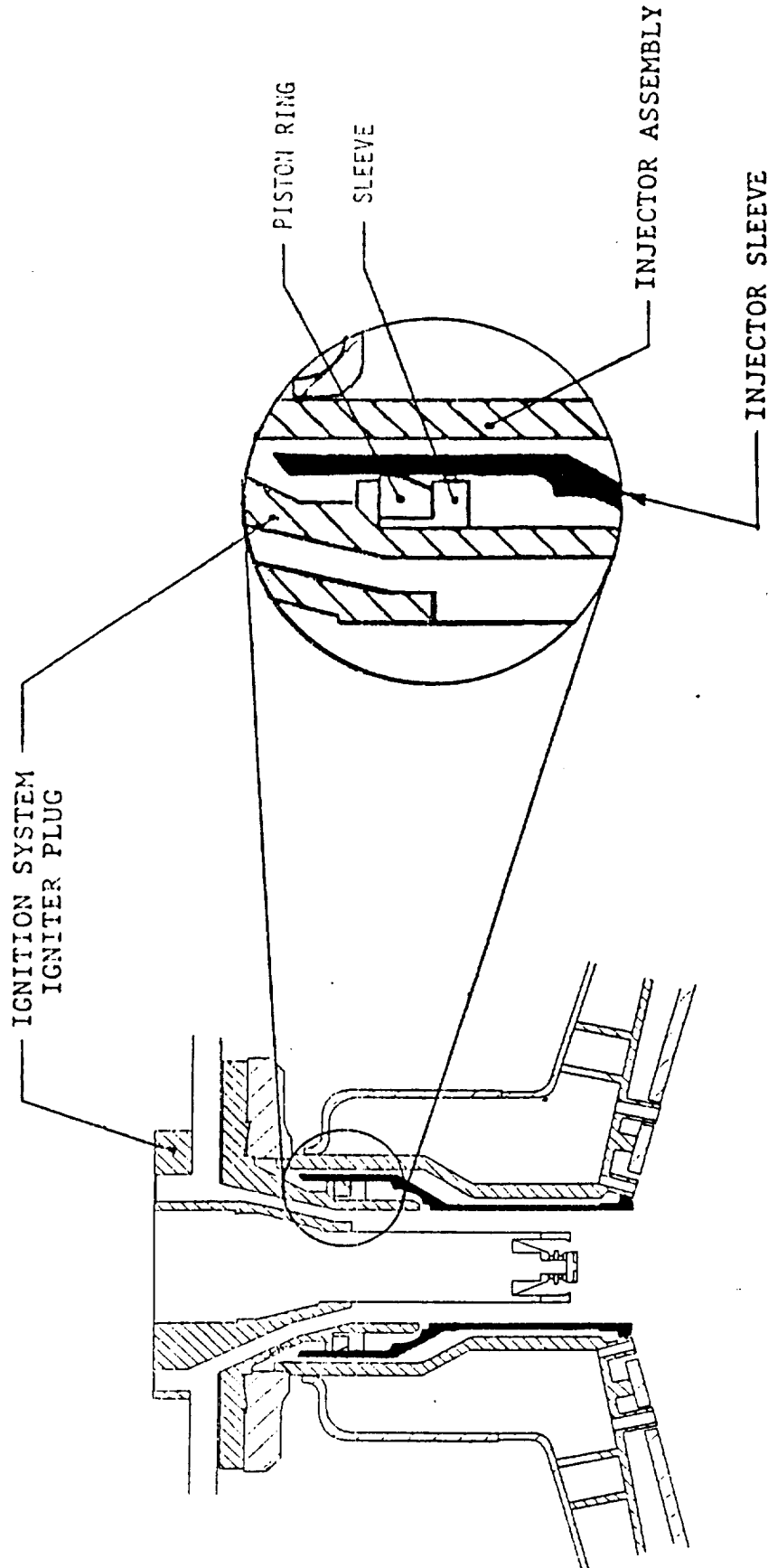


Figure 8. Chamber Pressure Trace for XR103-3 Run 41.01 Showing Igniter Light-Off and Chamber Light



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Figure 9. Igniter "Torching" Phenomenon



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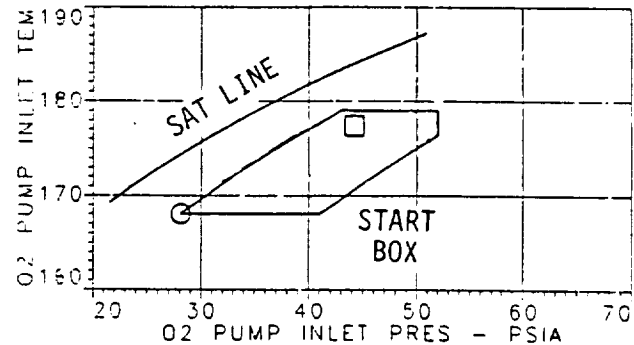
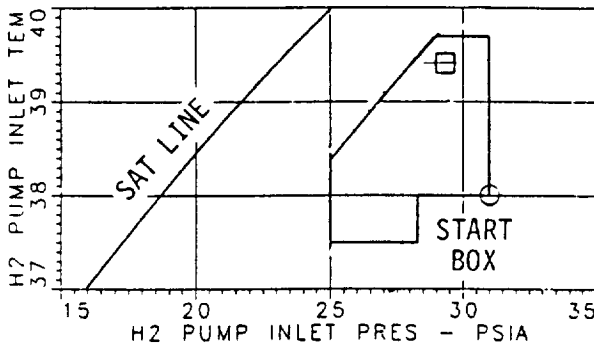
Figure 10. RL10 Igniter Leakage Control — Proposed Configuration Piston Ring Design Provides Controlled Leakage

SECTION 4.0 ATLAS/CENTAUR IGNITION

An investigation was made of the impact of the igniter H_2 leakage flow on Atlas/Centaur configuration igniter mixture ratio. Figure 11 shows the Atlas/Centaur start boxes, indicating run 53 inlet conditions as well as worst case conditions for igniter mixture ratio. A transient start simulation was used to predict igniter and chamber propellant flows at the worst case inlet conditions as indicated. The chamber is always in its ignition bucket, however, the figure shows that worst case specification inlet conditions combined with the largest leakage area causes the igniter to be out of its ignition bucket. For comparison, refer to run 53 plots in Appendix A. Also shown in Figure 11 is the case of worst inlet conditions with minimum leakage, as would be the case if the leakage control scheme outlined earlier were implemented. Here, igniter conditions are well within the bucket for most of the transient when ignition would occur. Hence, the desirability of a leakage control scheme for Atlas/Centaur is apparent.

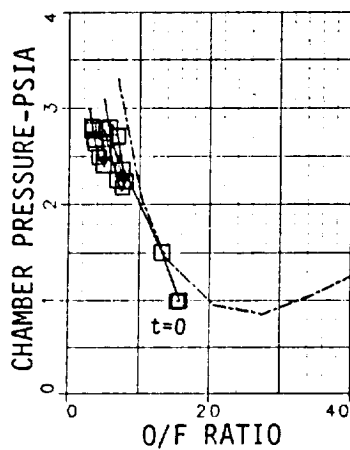
An ignition study was done for Atlas/Centaur launch No. 66 (AC-66) using the predicted inlet conditions. The worst case inlet conditions were used for both starts as shown in Figure 12. The igniter conditions were predicted using an RL10 transient start simulation program. The results are illustrated in Figure 13. The top two figures show igniter conditions assuming nominal igniter flow areas and nominal leakage size (0.00125 in. gap) with the worst case inlet conditions (Figure 12). These conditions would be those normally expected, and as shown, the igniter is well within the ignitable region for most of the transient. The bottom two plots show what happens if all worst case tolerances are considered (maximum H_2 area and minimum O_2 area) along with the largest leakage area and worst inlet conditions. The igniter is still within the ignition bucket during the initial part of the transient, when ignition should occur, but does move out of the bucket at about 0.22 second.

- - RUN 53 INLET CONDITIONS
○ - WORST CASE INLET CONDITIONS FOR IGNITOR



-----RL10 IGNITER BUCKET- MIN LEAK

PREDICTED
0-.6 SEC TRANSIENT



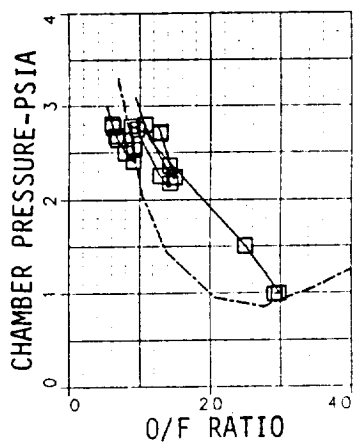
NOTE: P_c vs O/F FOR RUN 53 IS IN APPENDIX A

← CURRENTLY:
IGNITOR OUT OF START BOX WITH ALL
WORST CASE CONDITIONS:

MAX H2 IGNITOR LEAKAGE AREA, ORIFICE SIZE & CD

MIN O2 IGNITOR AREA & CD

WORST CASE INLET CONDITIONS



← WITH H2 LEAKAGE CONTROL:
REDUCING LEAKAGE TO MIN MOVES IGNITOR INTO
BUCKET EVEN WITH ALL OTHER CONDITIONS
WORST CASE (AS ABOVE).

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Figure 11. Atlas/Centaur Ignition Summary With Worst Case Inlet Conditions

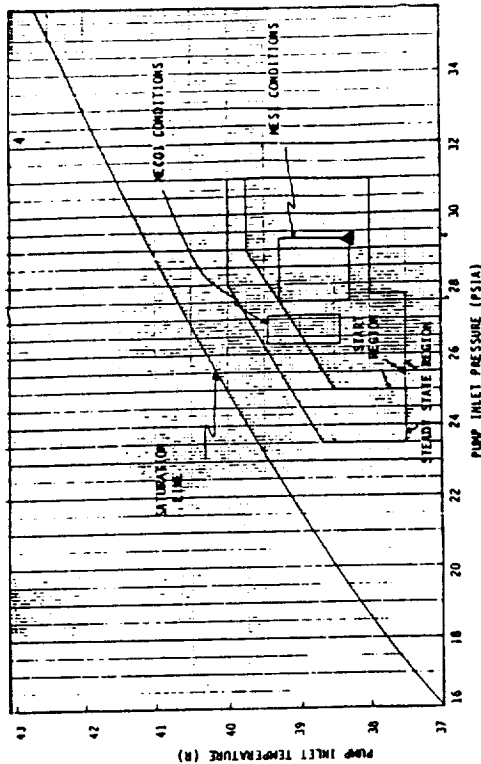


Figure 3. LH₂ Tank Pump Inlet Conditions for AC-66 First Burn

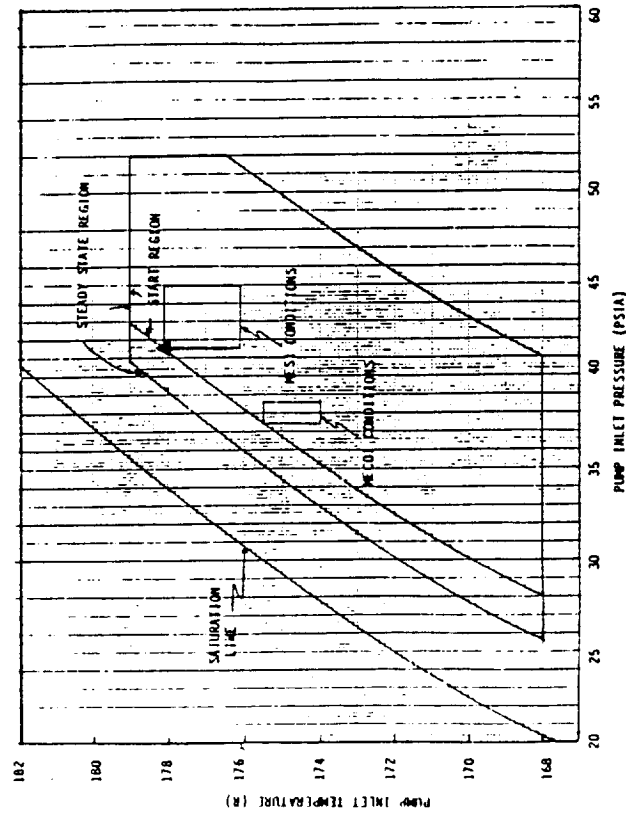
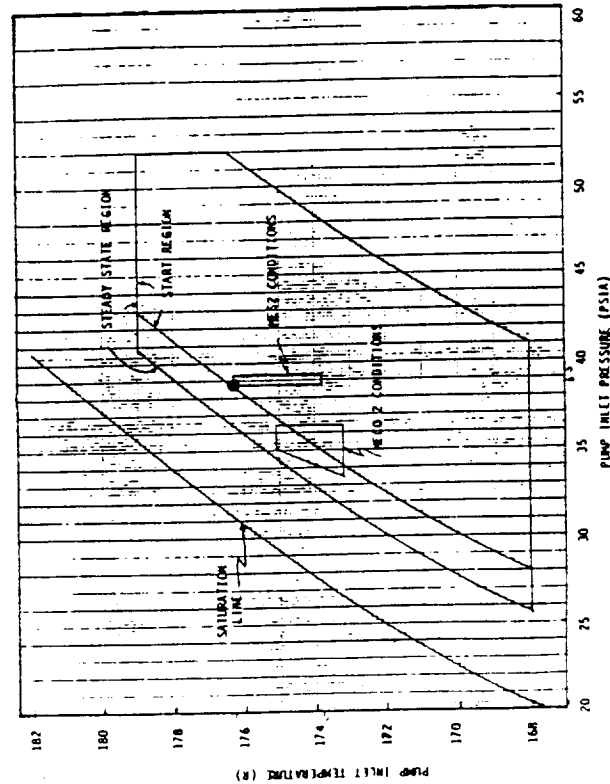
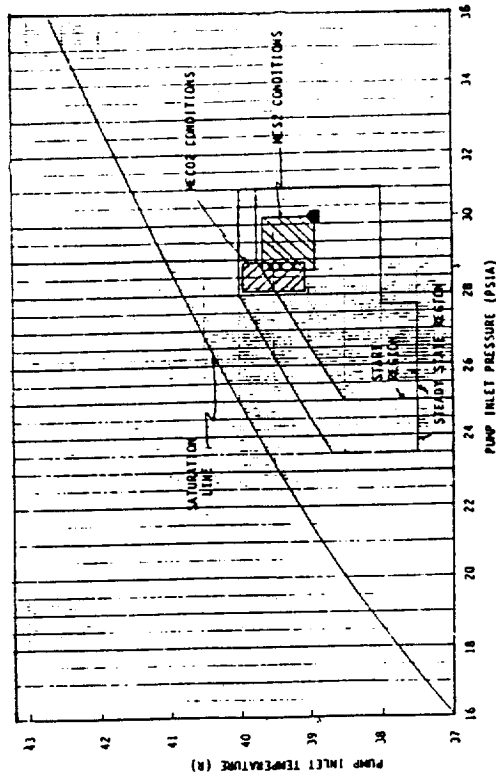


Figure 1. LO₂ Tank Pump Inlet Conditions for AC-66 First Burn

▲ WORST CASE FIRST START CONDITIONS

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Figure 12. AC-66 Inlet Conditions — First and Second Starts (Sheet 1 of 2)

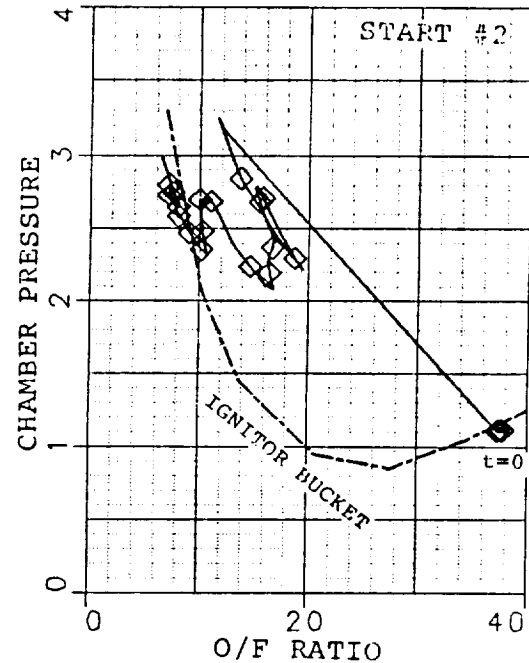
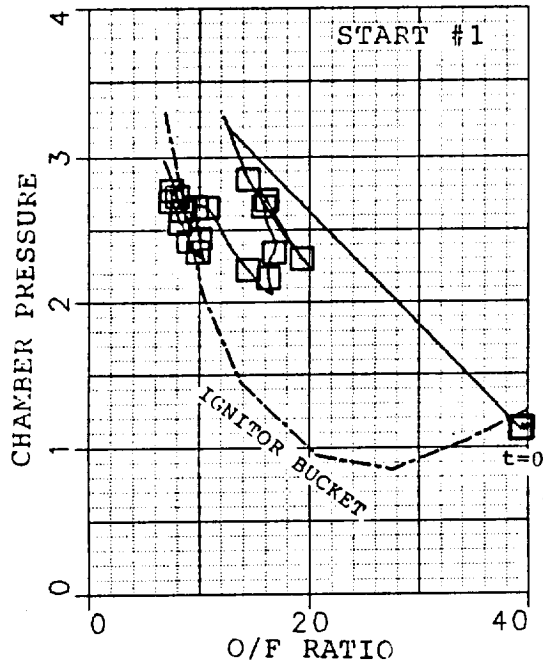


WORST CASE SECOND START CONDITIONS

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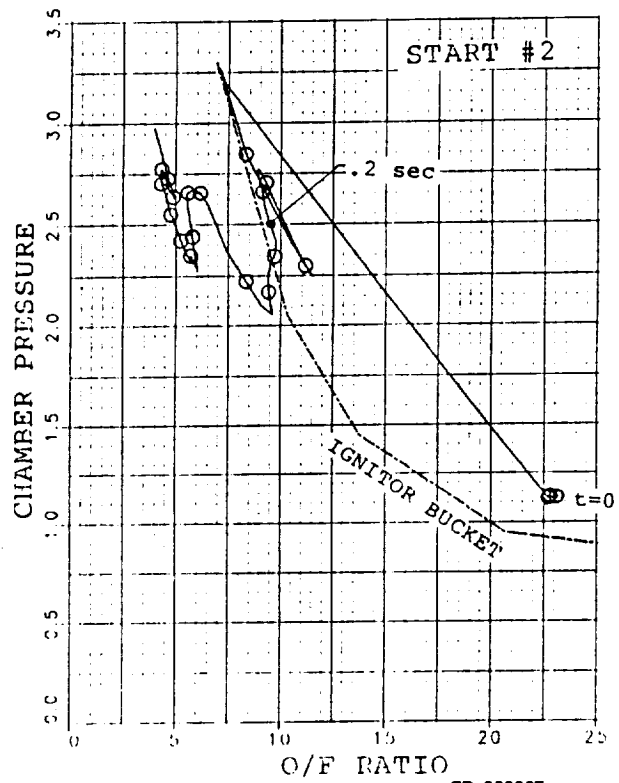
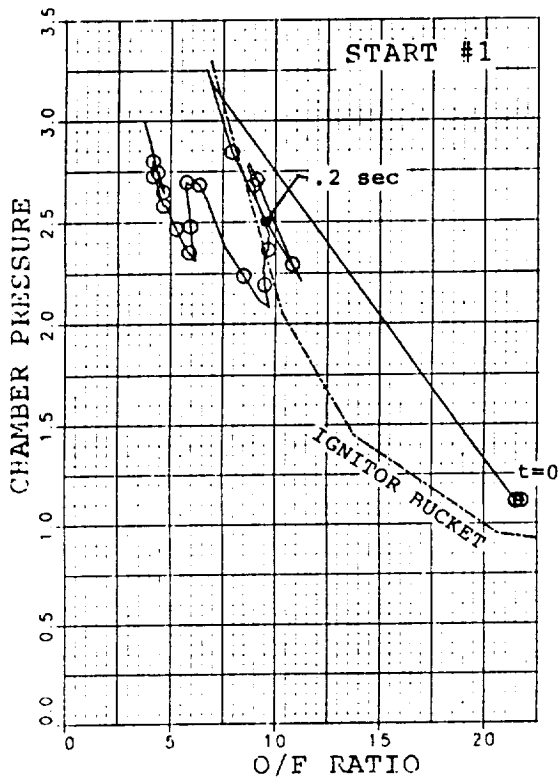
Figure 12. AC-66 Inlet Conditions — First and Second Starts (Sheet 2 of 2)

NOMINAL IGNITOR AREAS & NOMINAL LEAKAGE AREA:



NOTE: SYMBOLS ARE PLOTTED AT .030 SEC INTERVALS

WORST CASE IGNITOR AREAS & LARGEST LEAKAGE:



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Figure 13. AC-66 Predicted Igniter Conditions

SECTION 5.0 CONCLUSIONS

- Increased igniter oxygen flow for Shuttle/Centaur is desirable. Testing of several configurations of increased flow GOX valve plumbing, and an igniter with increased diameter oxygen holes (0.082 vs 0.068 B/M) indicated that more oxidizer to the igniter results in quicker chamber ignition.
- O-graph data shows that the igniter generally lights on the first spark, and then "torches" until enough energy is produced to light the chamber. Chamber ignition was seen to occur between sparks and even after the shutdown signal, supporting the theory of igniter torching.
- A hydrogen leakage path in the igniter, which has been overlooked in previous ignition investigations, has been identified. The injector/igniter clearance gap (minimum 0.0005 in., maximum 0.002 in.) creates H_2 leakage between 30 percent and 180 percent of the nominal flow through the igniter fuel holes. Incorporation of a seal to control this leakage to the 30 percent level is recommended.
- P_c vs igniter O/F ratio at ignition for the runs made in this investigation agree very well with the original RL10 ignition bucket (from Ref. 1), once corrected for H_2 leakage.
- Start transient modeling for Atlas/Centaur shows that if an igniter with worst case leakage is combined with the worst case Atlas/Centaur specification inlet conditions (low LOX pressure, high fuel pressure), the igniter mixture ratio will be out of the start bucket. The possibility of this situation, even though unlikely, makes fuel leakage control mandatory for the full range of Atlas/Centaur specification inlet conditions. Until incorporation of this control the vehicle propellant inlet condition range must be limited.
- With the recommended igniter plumbing changes and igniter leakage control, the Shuttle/Centaur will successfully ignite throughout its specified inlet range.

APPENDIX A
XR103-3 IGNITION PLOTS

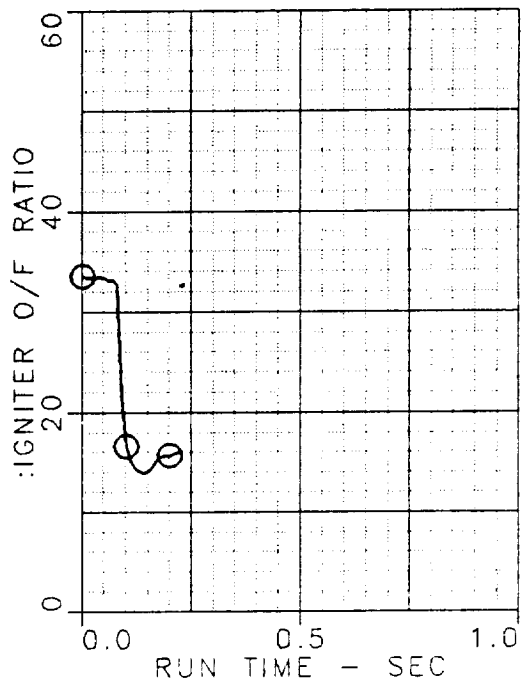
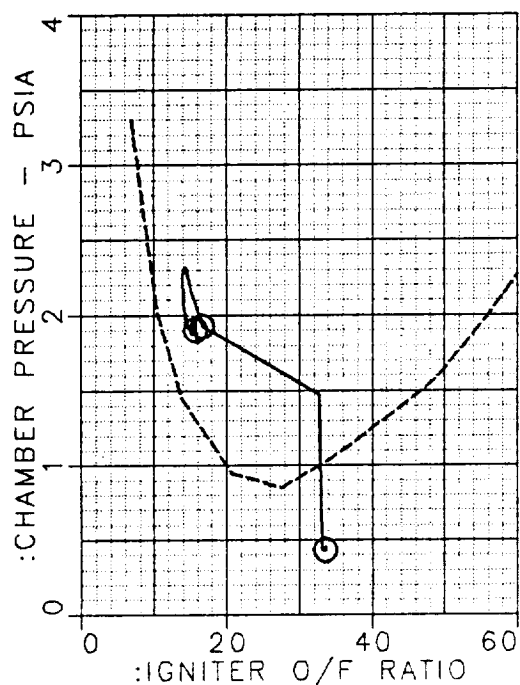
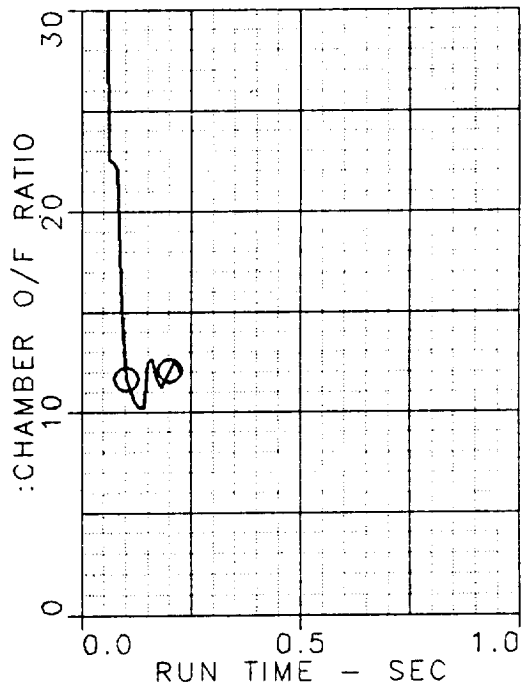
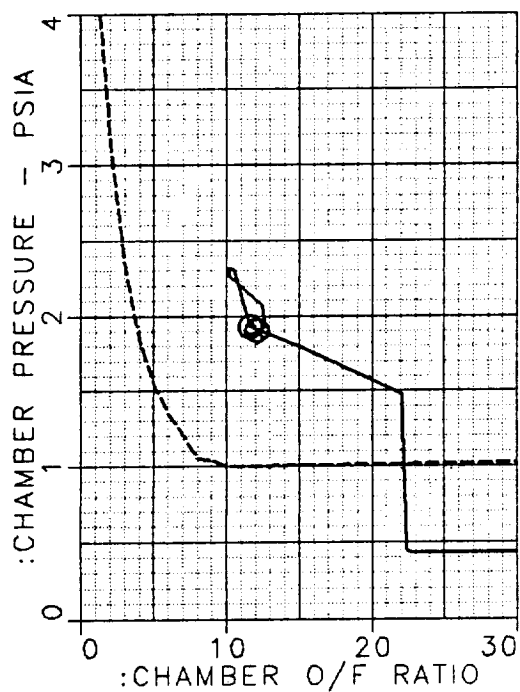
Plots of chamber pressure vs O/F mixture ratio and mixture ratio vs time are provided in Figures A-1 through A-19 for the XR103-3 ignition investigation. The following should be noted:

- The data on each page (4 plots) pertain to one run, starting with run 29
- Plots for runs 30, 31, 48-50, and 52 cannot be generated due to lack of data
- The chamber and igniter buckets are shown as dashed lines on the appropriate plots
- Symbols are plotted at 0.1 second intervals
- The end point of each transient plot corresponds to chamber ignition; This point is labeled only for run 29, but should be obvious for the others.

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

FR-19556-1

- 1—○—XR103-3 RUN 29.06 START
2-----RL10 CHAMBER IGNITION BUCKET
3-----RL10 IGNITER BUCKET- MIN LEAK

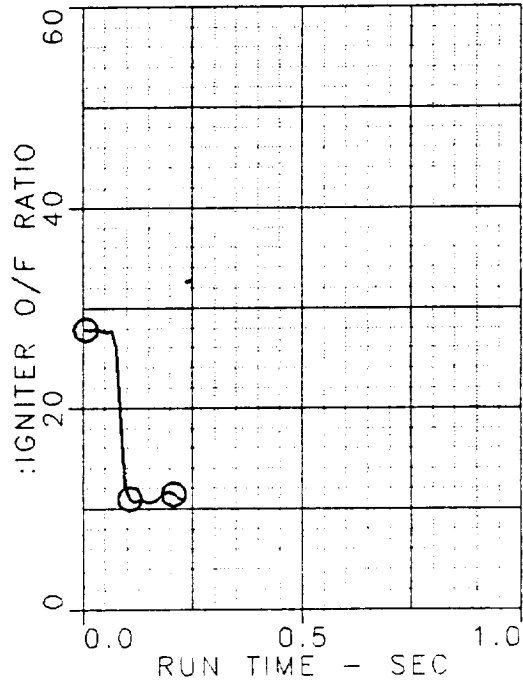
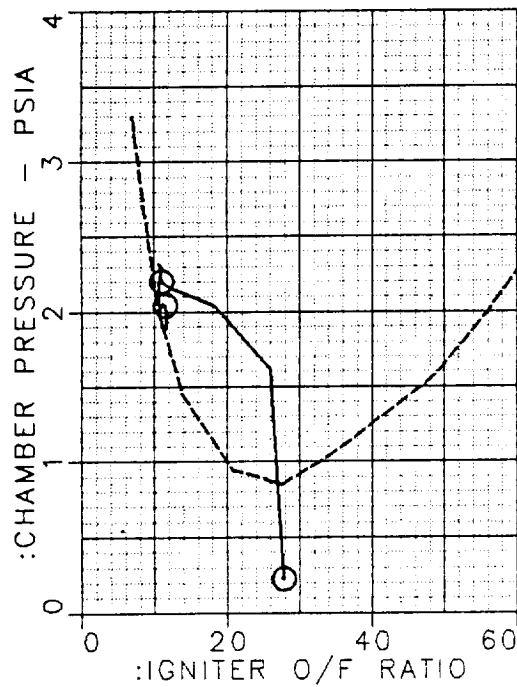
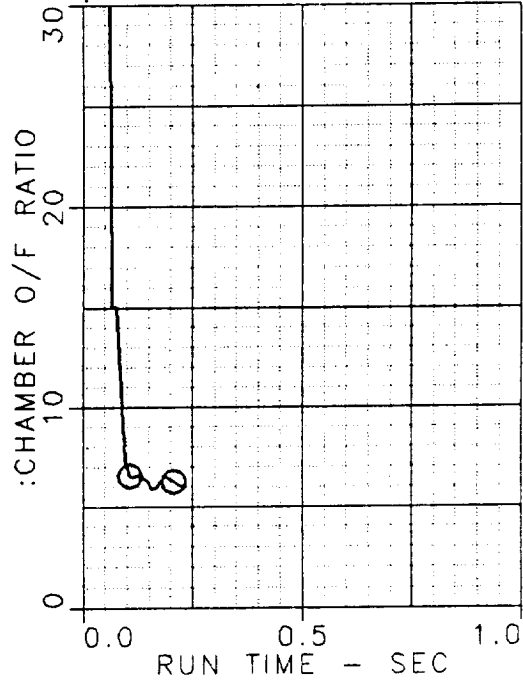
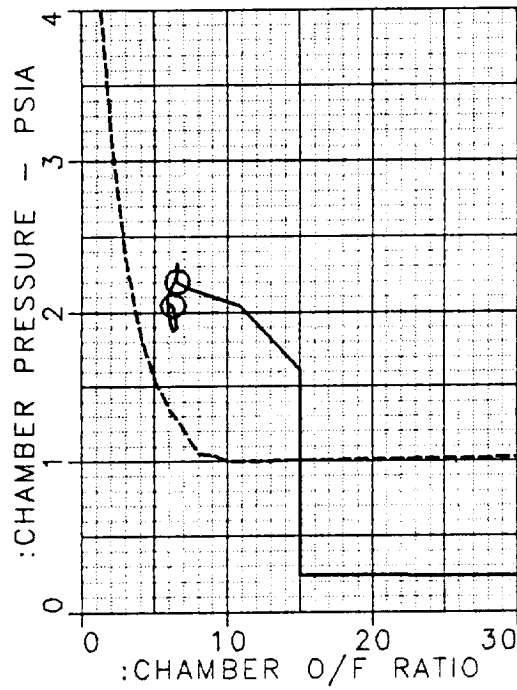


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Figure A-1. Run 29.06

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 30.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

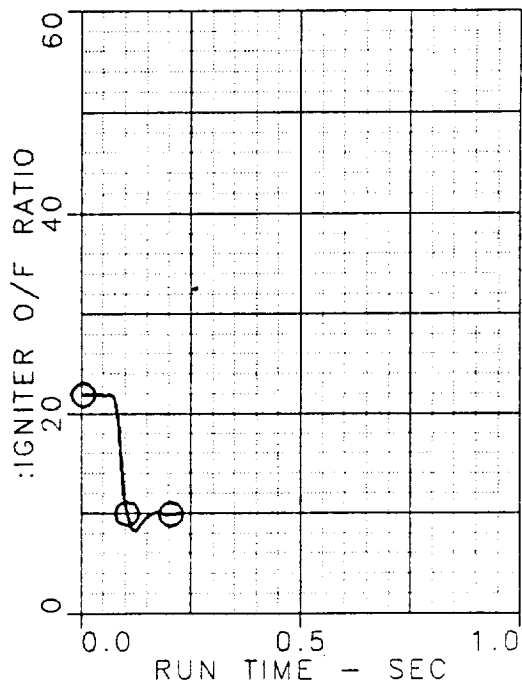
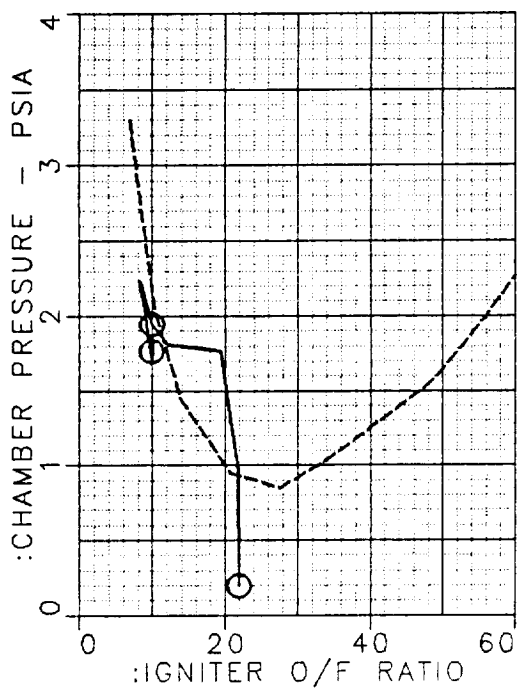
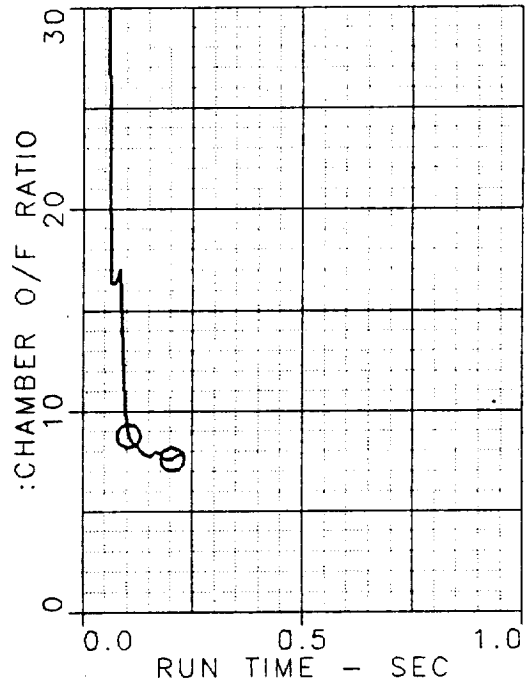
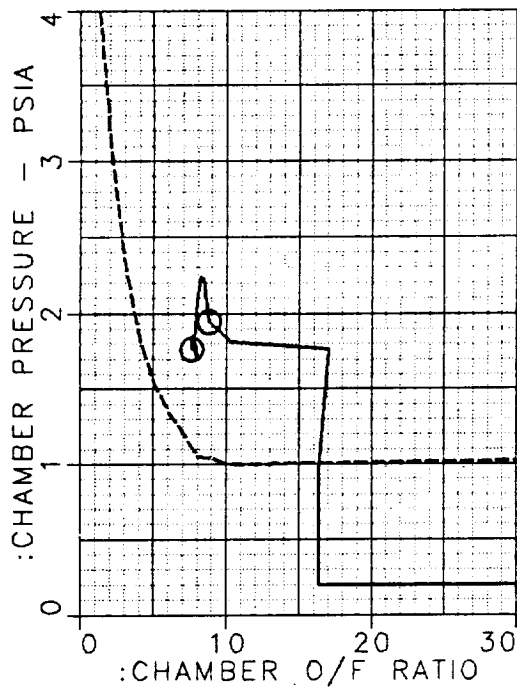


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Figure A-2. Run 30.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 33.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

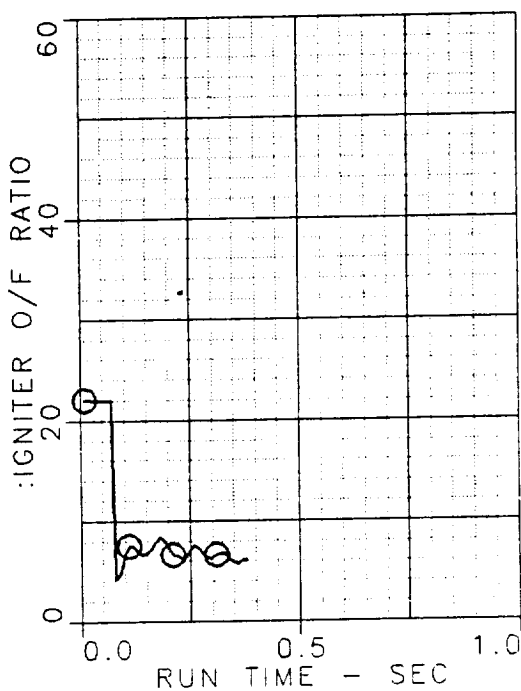
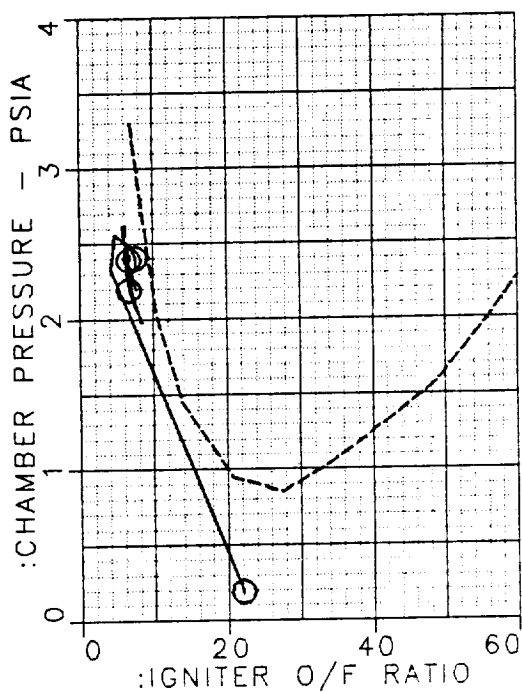
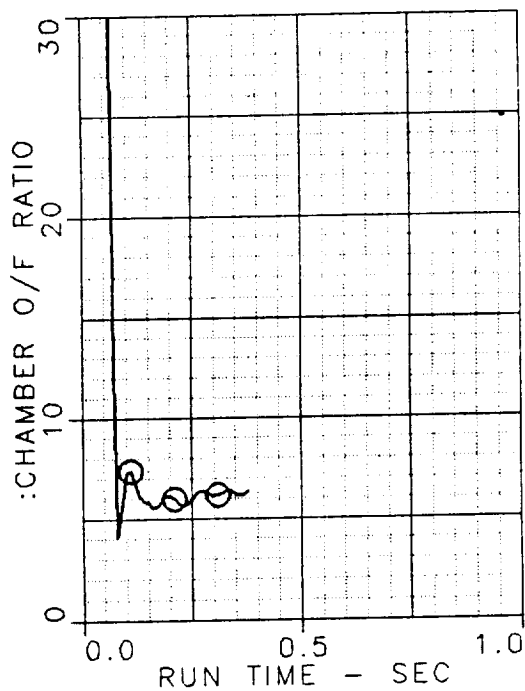
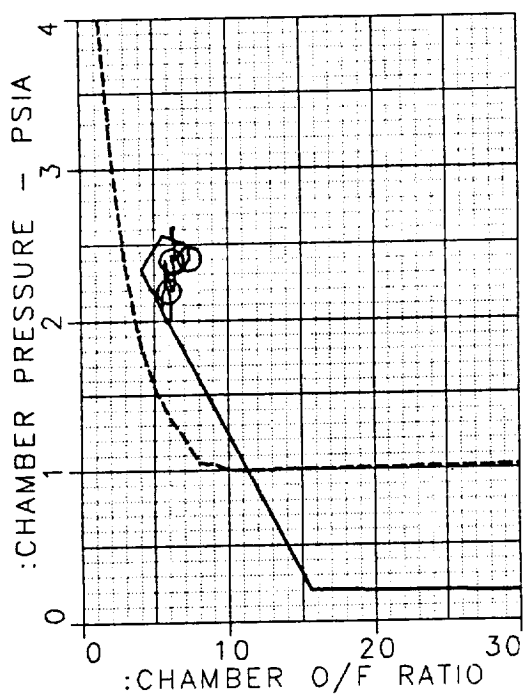


FD 320270

Figure A-3. Run 33.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 34.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

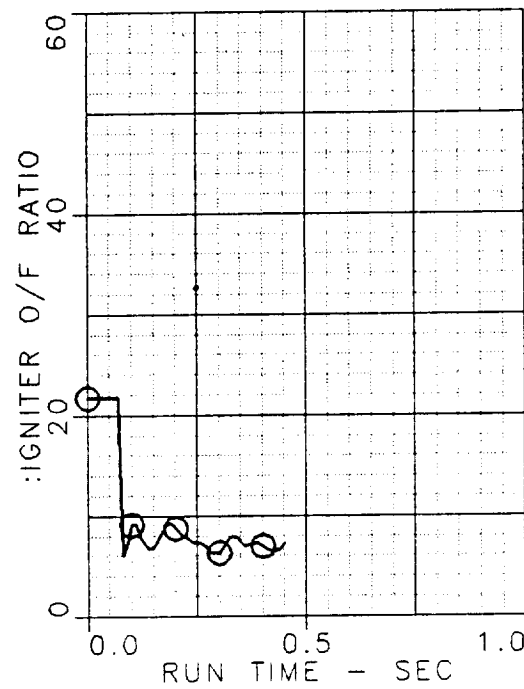
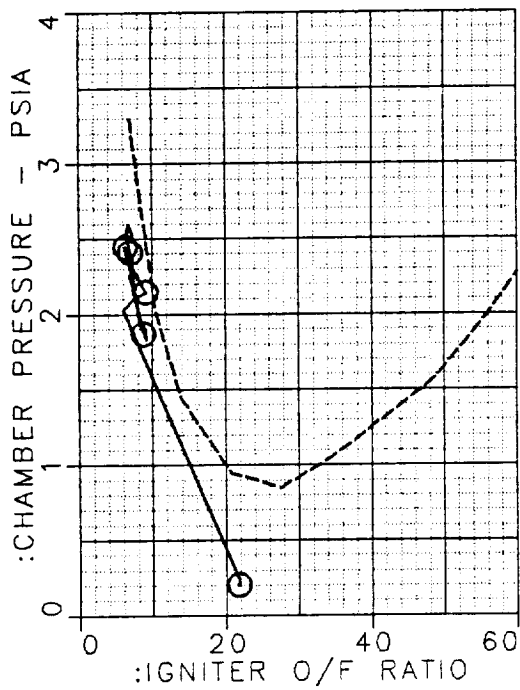
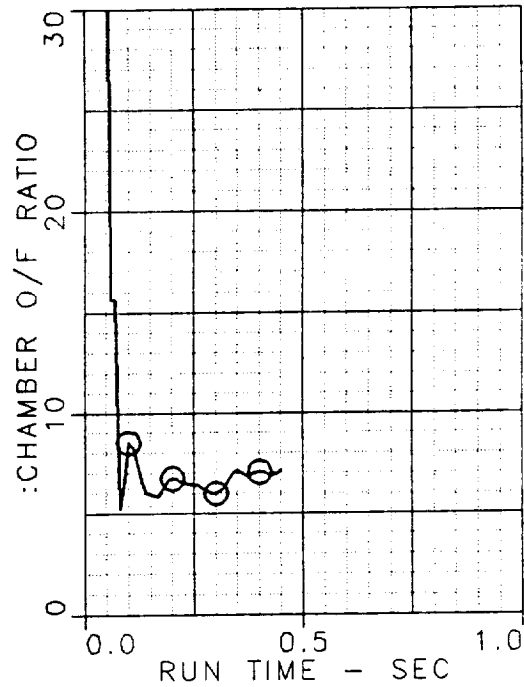
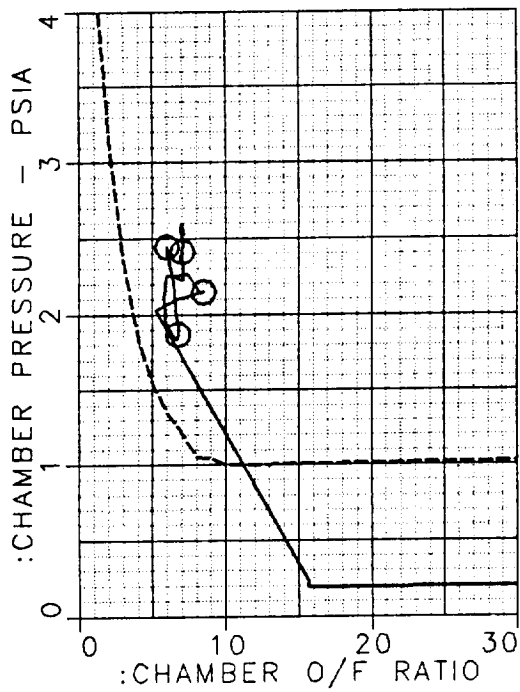


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Figure A-4. Run 34.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 35.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

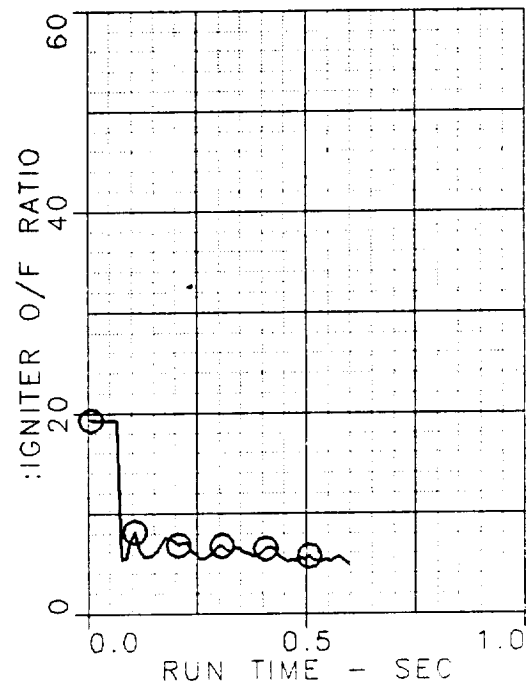
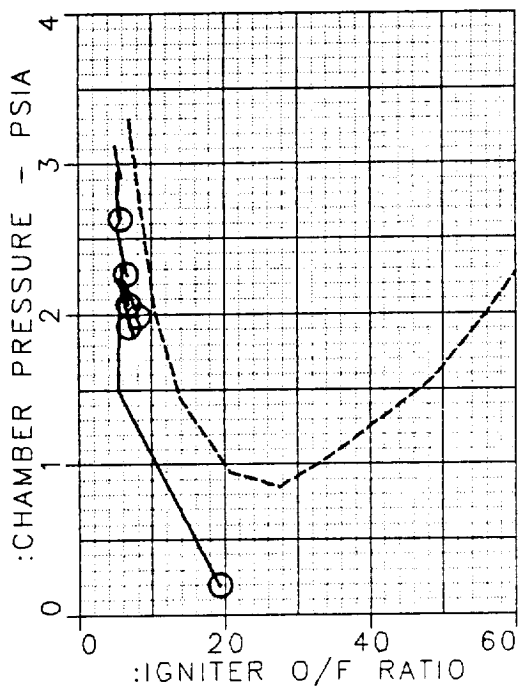
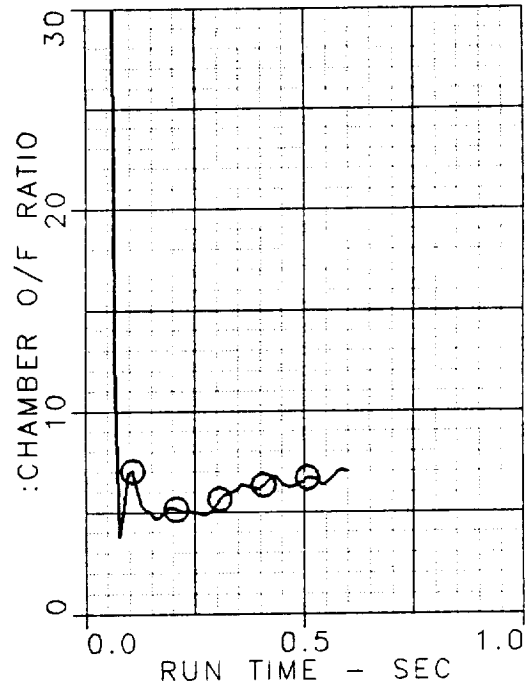
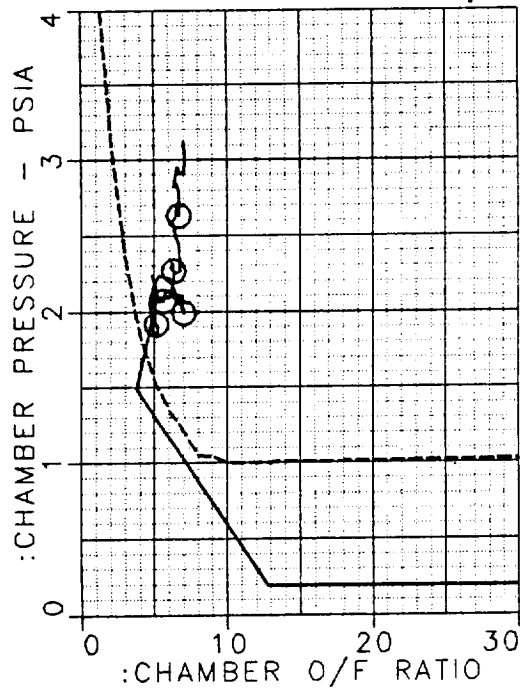


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Figure A-5. Run 35.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 36.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

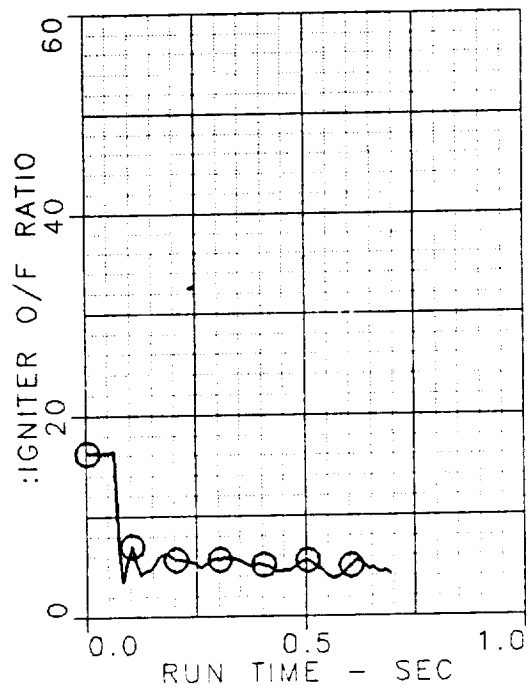
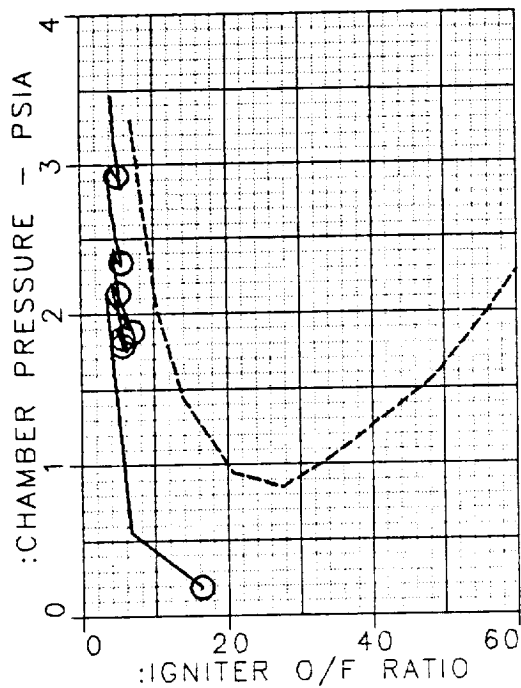
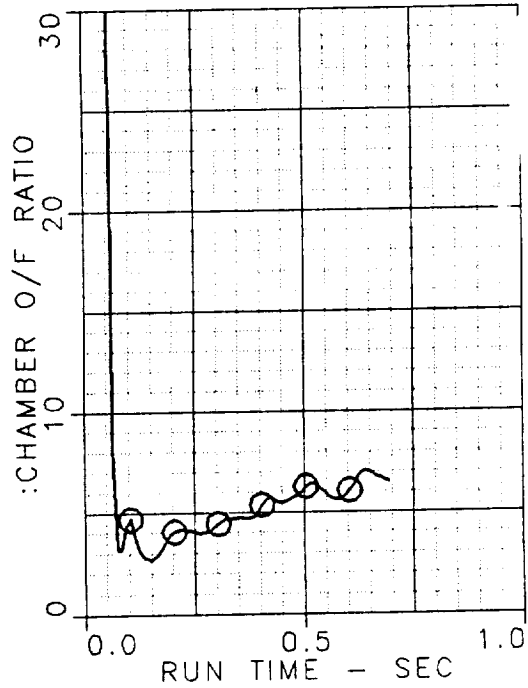
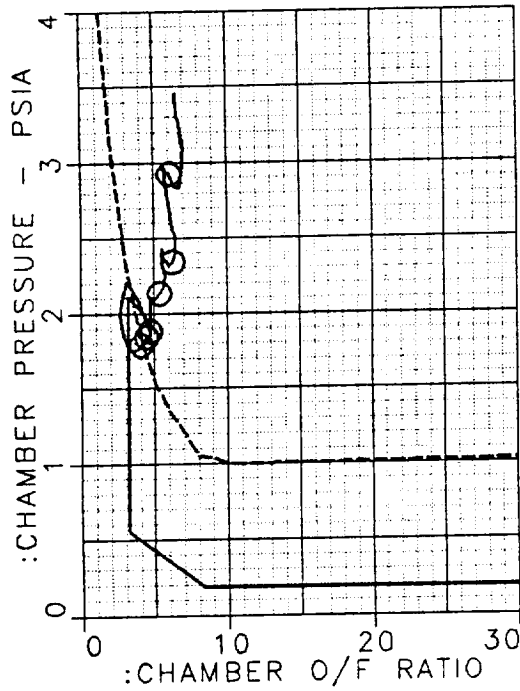


FD 320273

Figure A-6. Run 36.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 37.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

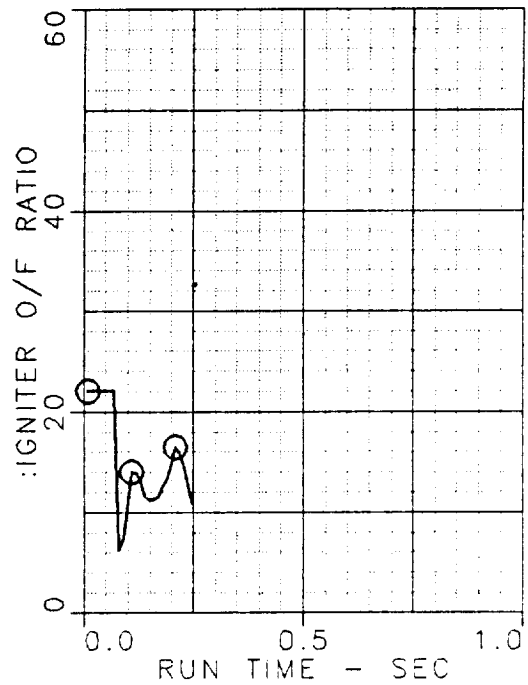
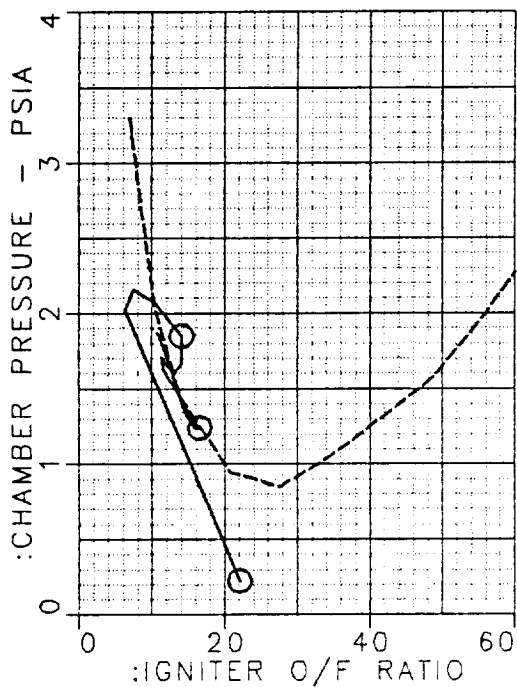
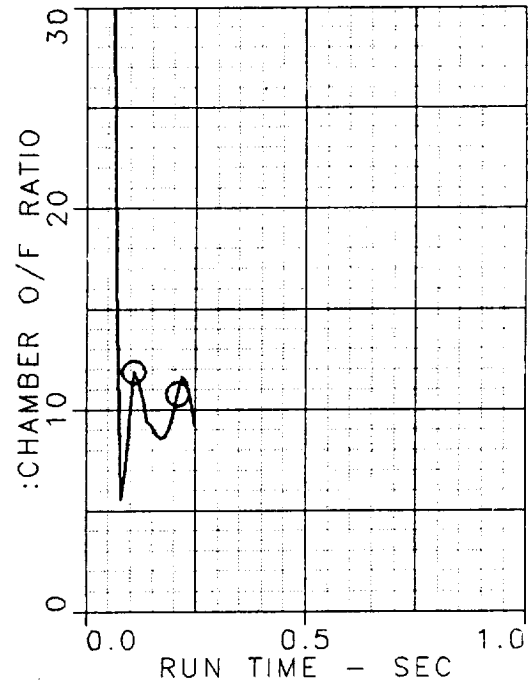
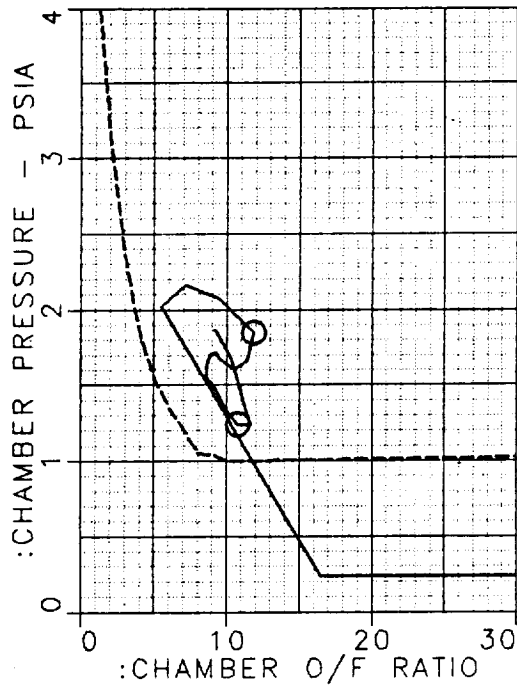


FD 320274

Figure A-7. Run 37.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 38.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

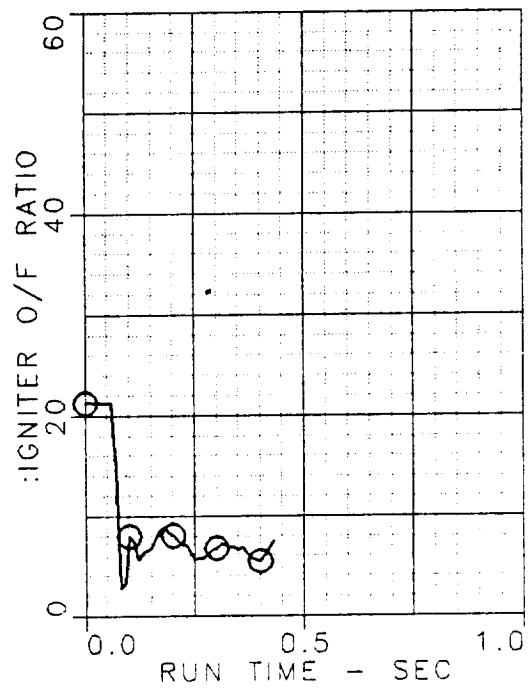
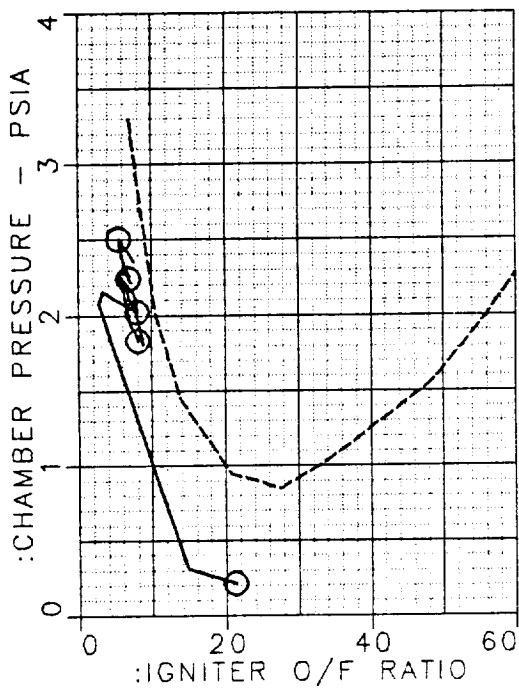
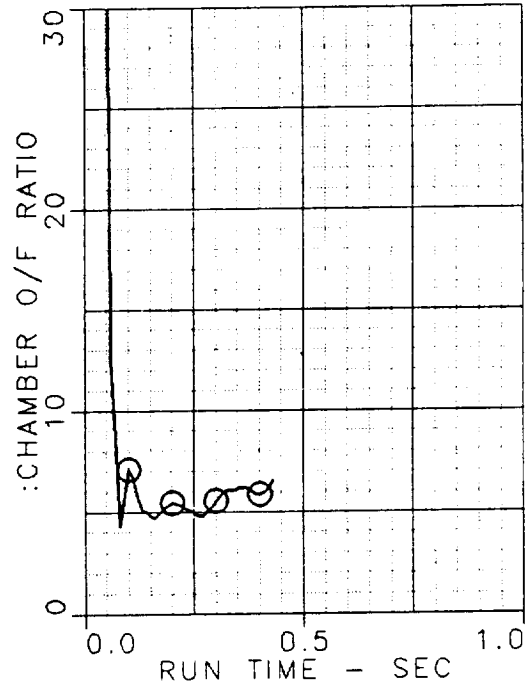
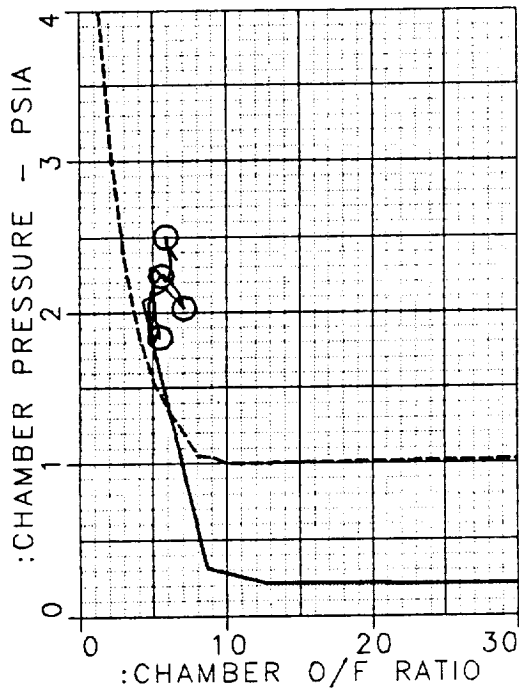


FD 320275

Figure A-8. Run 38.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 39.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

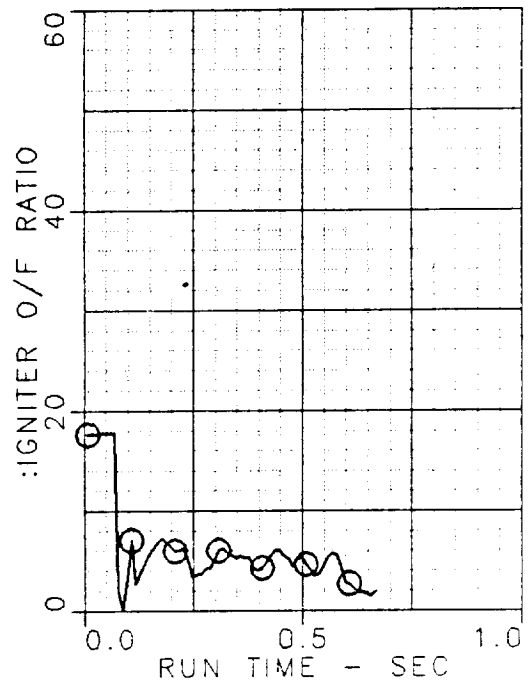
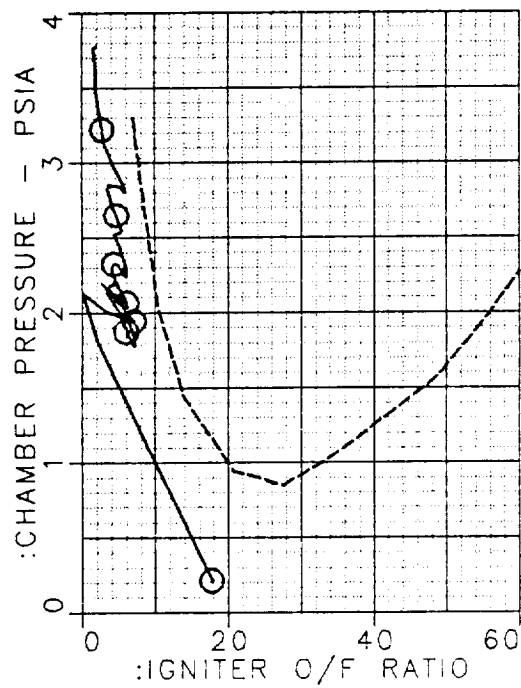
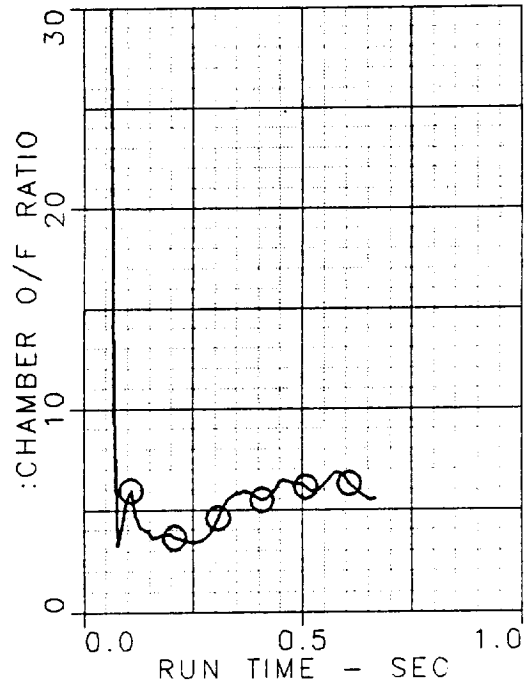
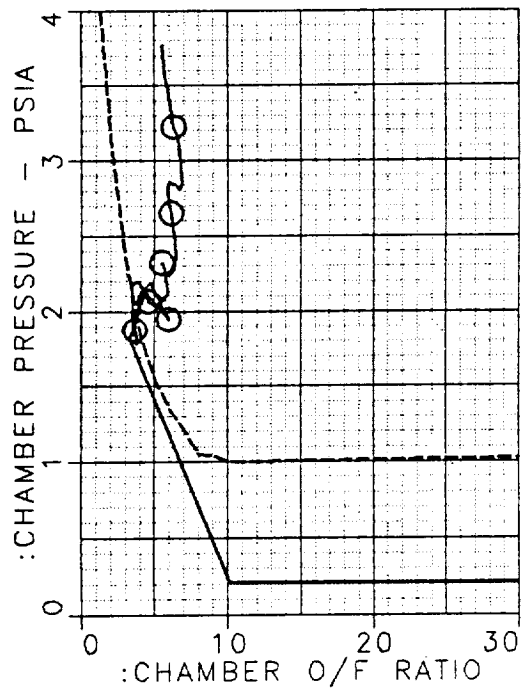


FD 320276

Figure A-9. Run 39.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 40.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

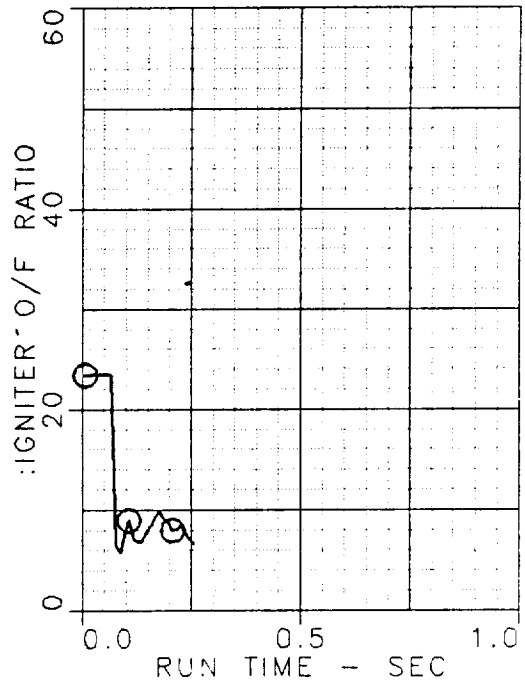
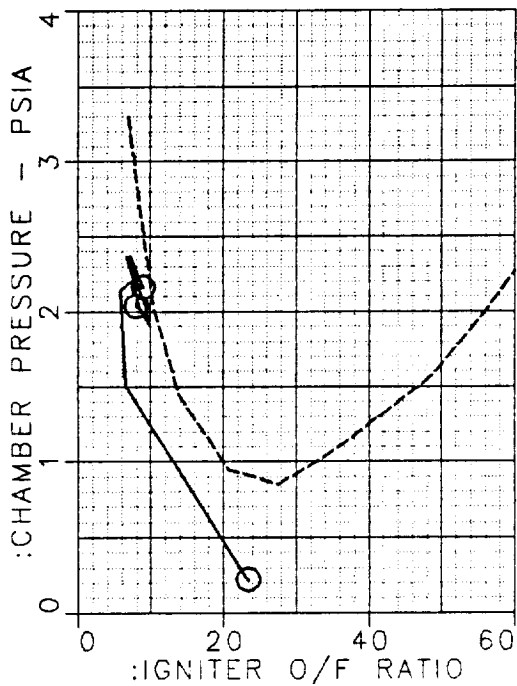
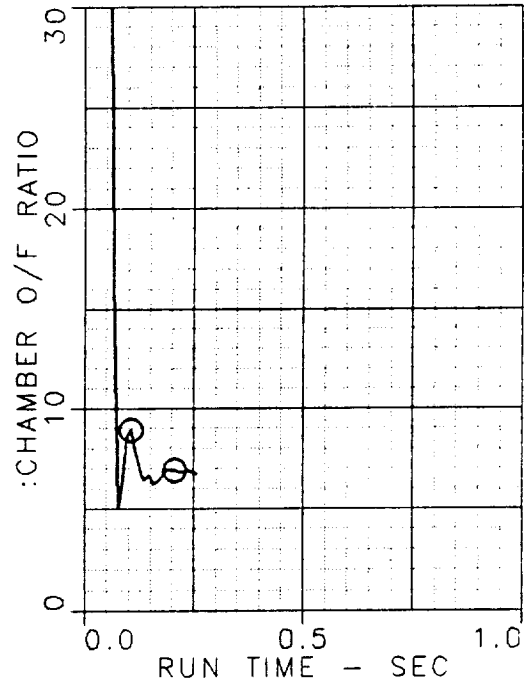
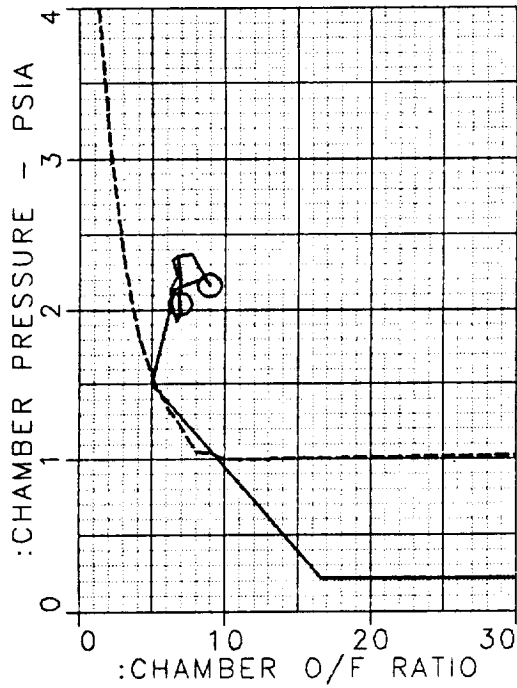


FD 320277

Figure A-10. Run 40.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 41.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

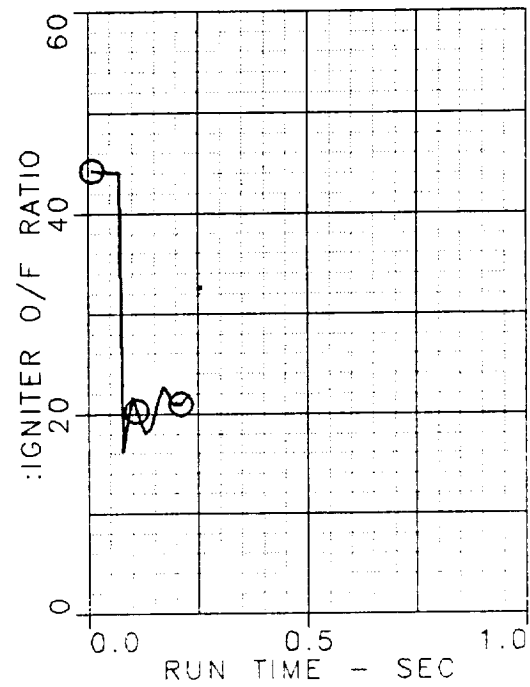
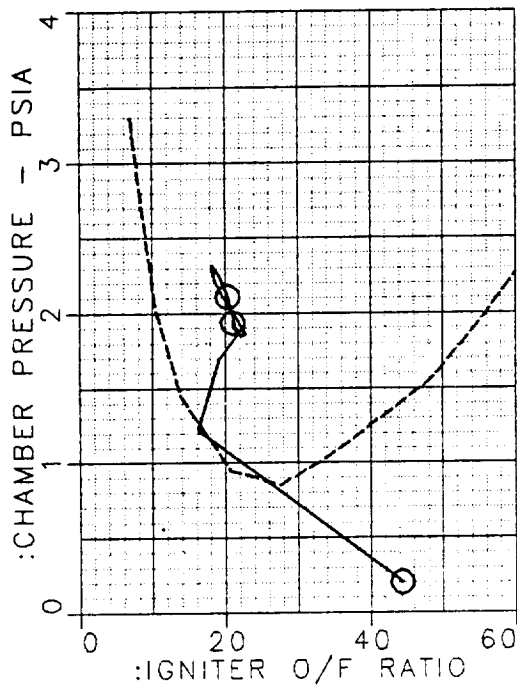
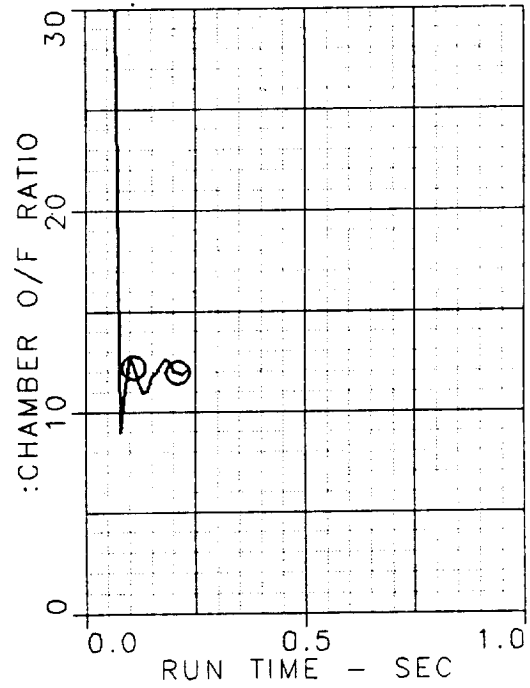
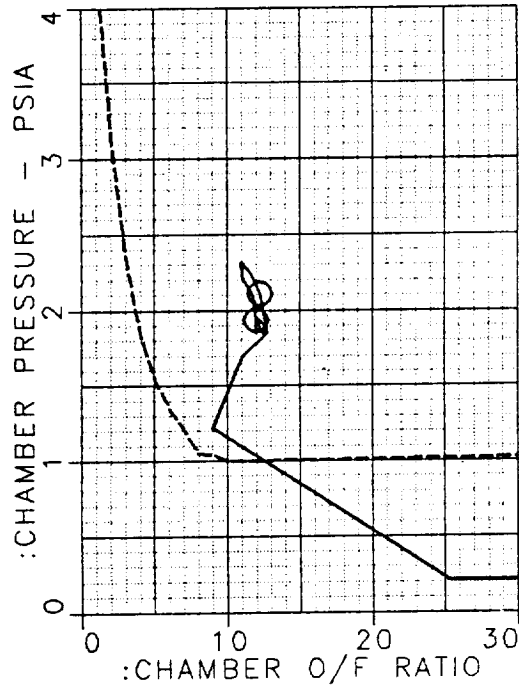


FD 320278

Figure A-11. Run 41.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 42.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

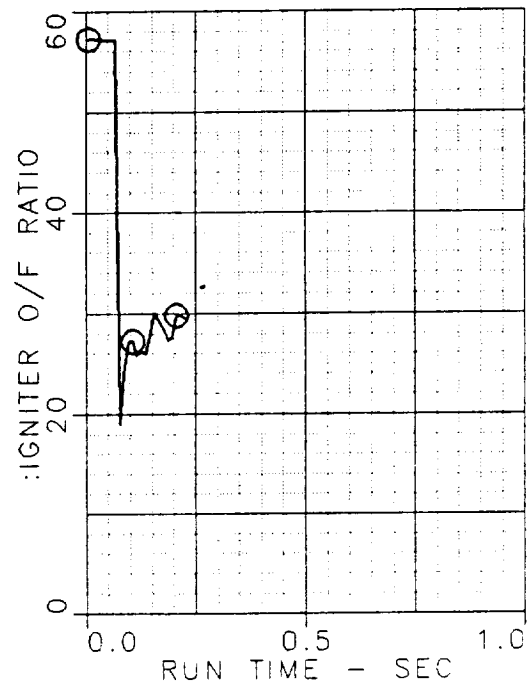
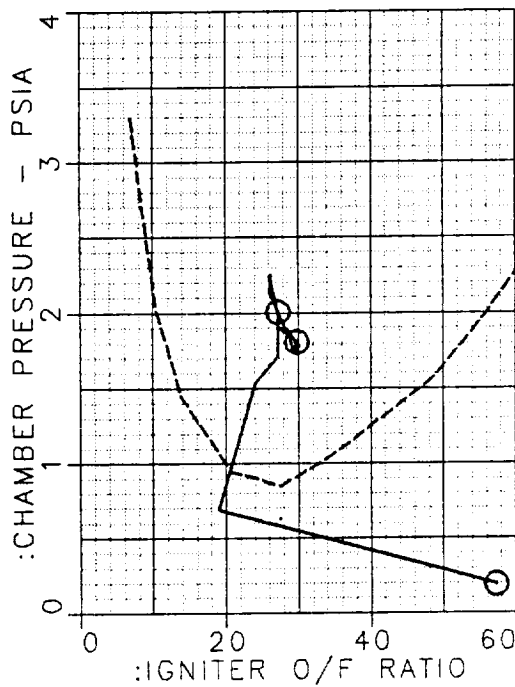
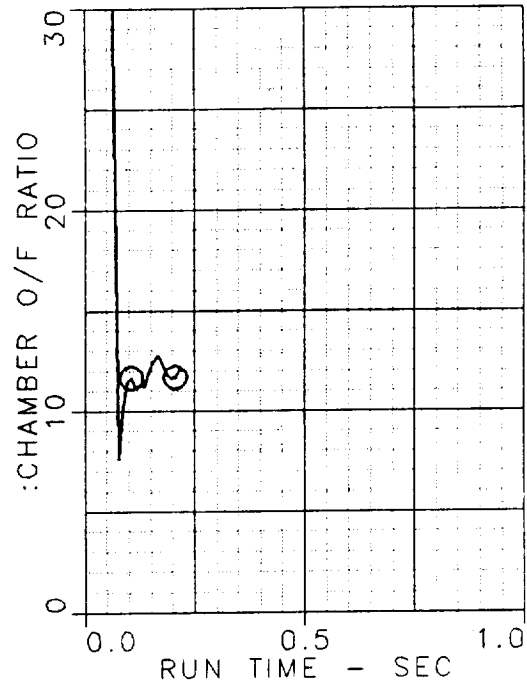
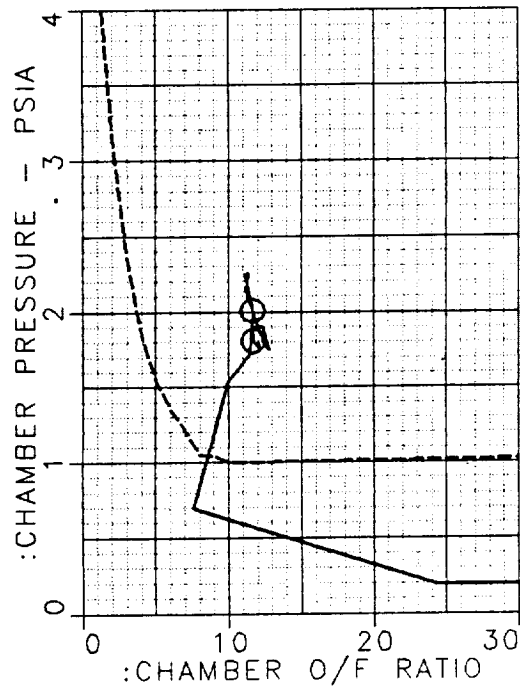


FD 320279

Figure A-12. Run 42.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 43.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK



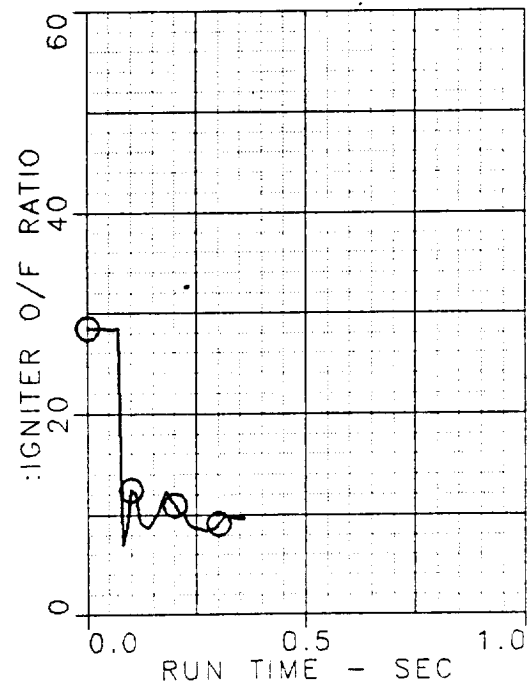
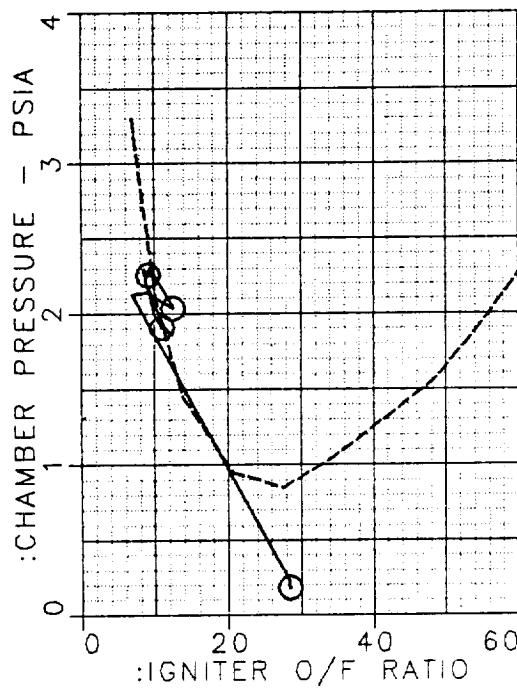
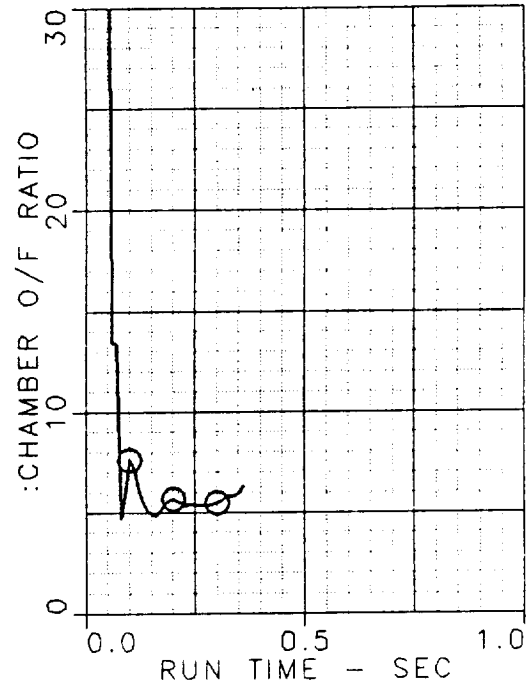
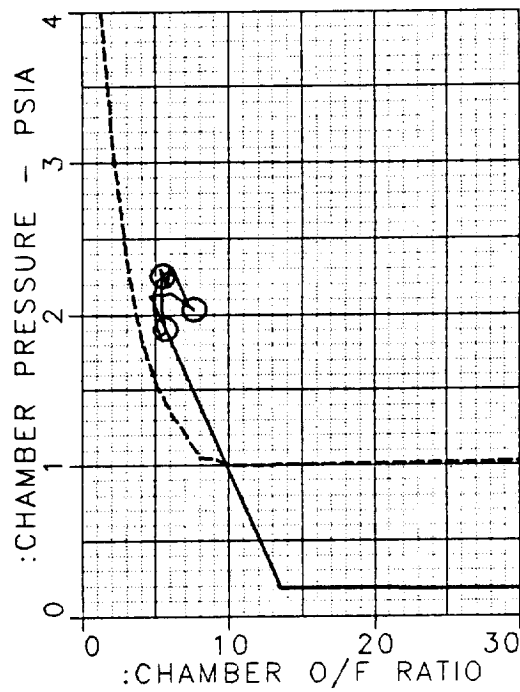
FD 320280

Figure A-13. Run 43.01

PRATT & WHITNEY, ROCKET PERFORMANCE

SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 44.01 (OIMP12 TRANSFERRED FROM R36)
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK



FD 320281

Figure A-14. Run 44.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 45.01 START
2-----RL10 CHAMBER IGNITION BUCKET
3-----RL10 IGNITER BUCKET- MIN LEAK

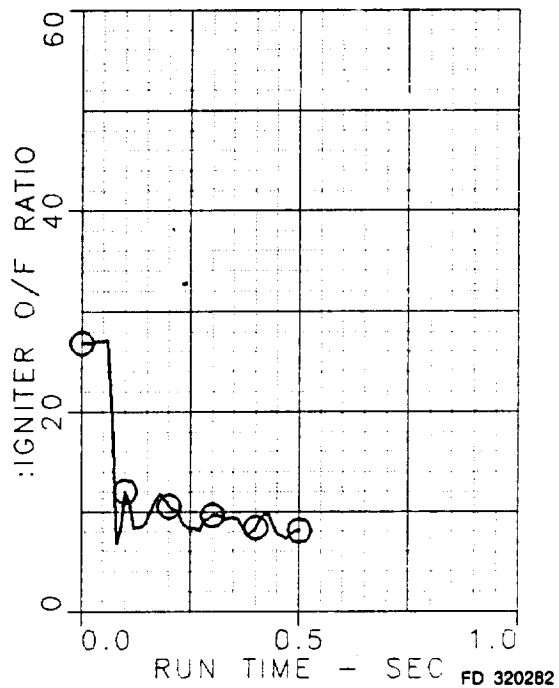
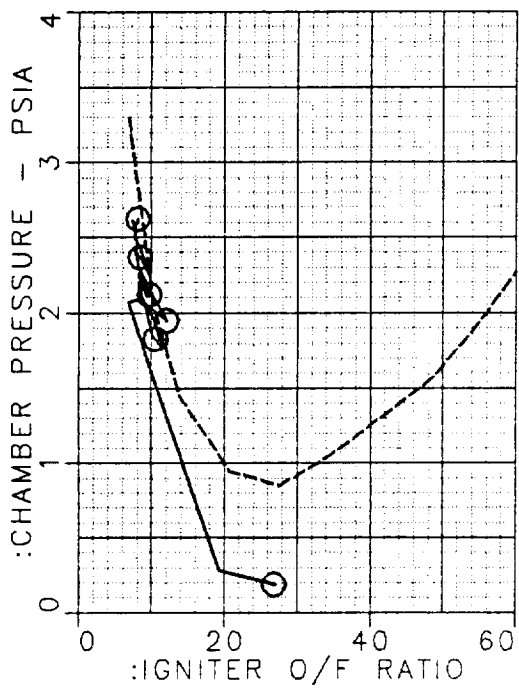
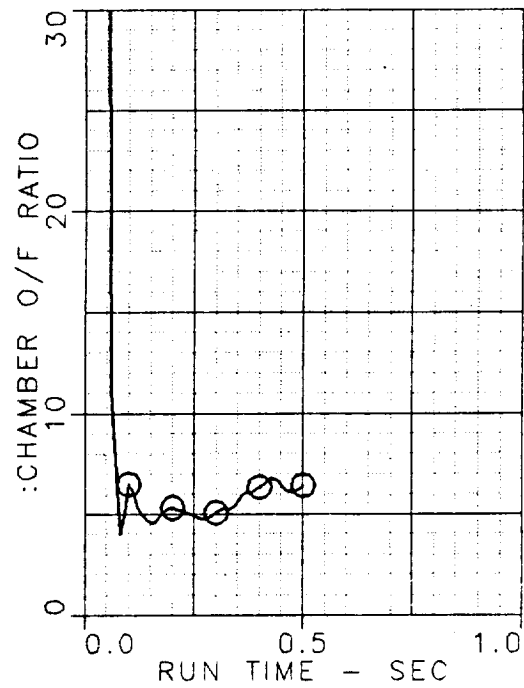
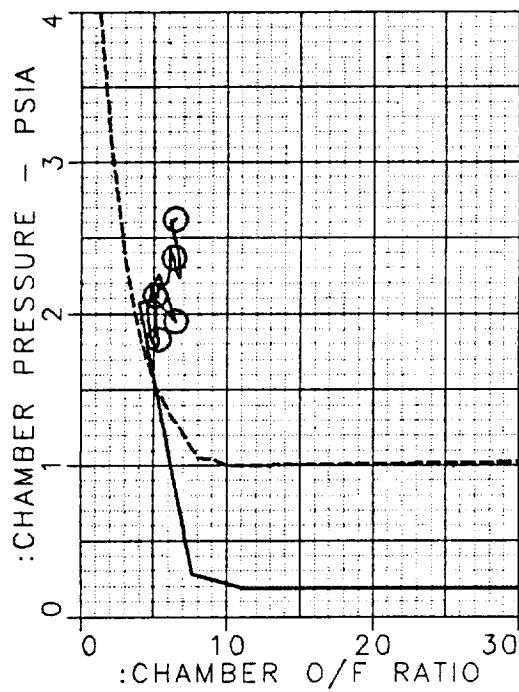
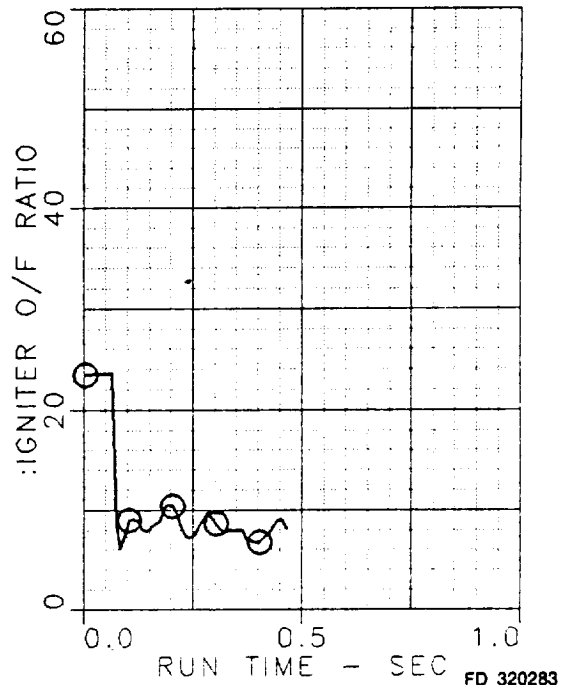
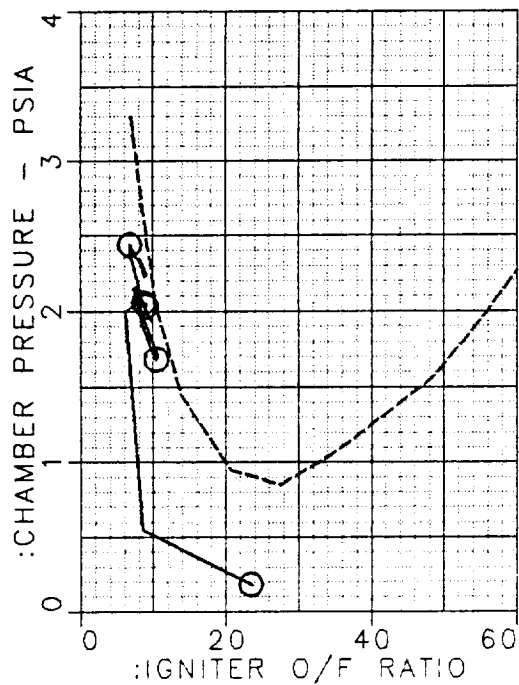
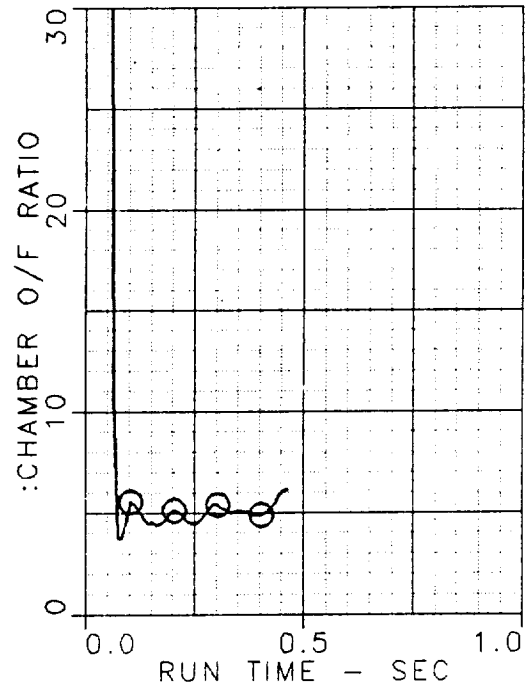
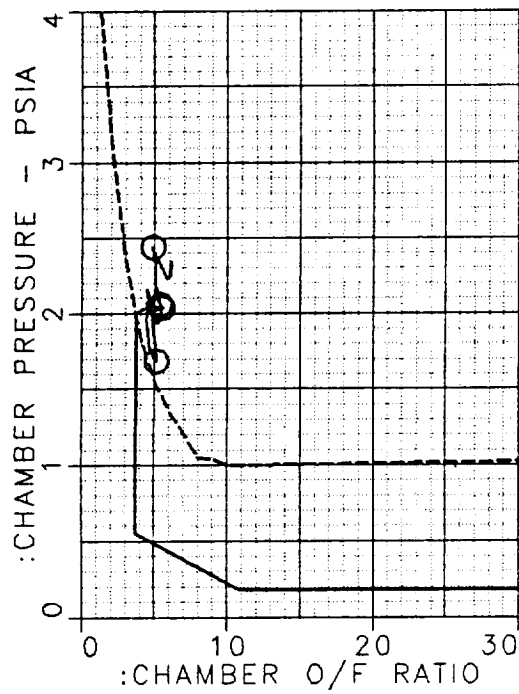


Figure A-15. Run 45.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 46.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK



FD 320283

Figure A-16. Run 46.01

PRATT & WHITNEY, ROCKET PERFORMANCE SHUTTLE/CENTAUR IGNITION STUDY

- 1—○ XR103-3 RUN 47.01 START
 2-----RL10 CHAMBER IGNITION BUCKET
 3-----RL10 IGNITER BUCKET- MIN LEAK

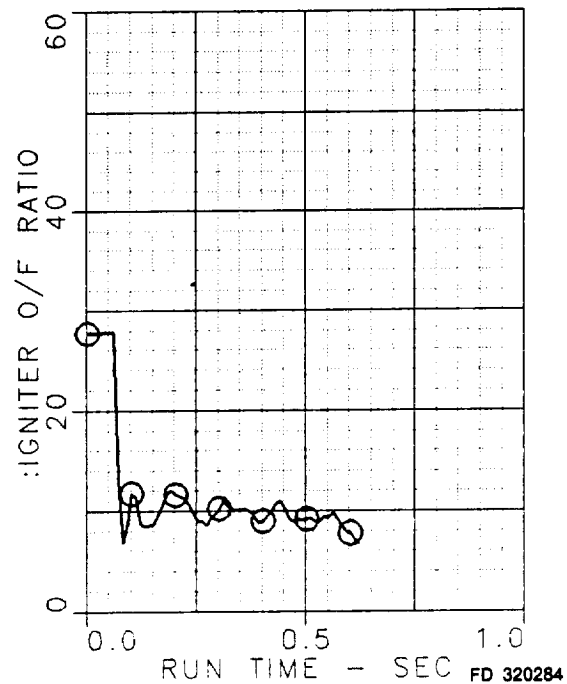
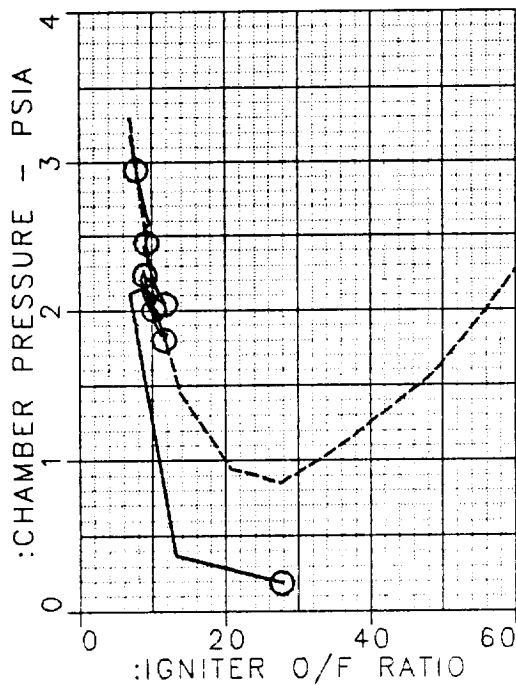
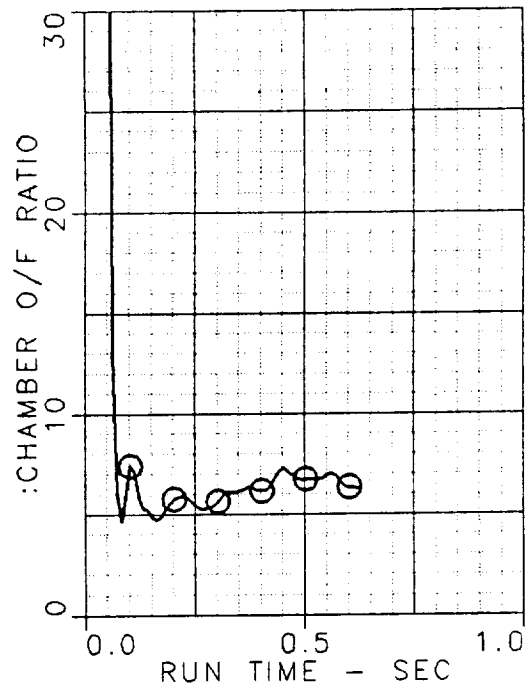
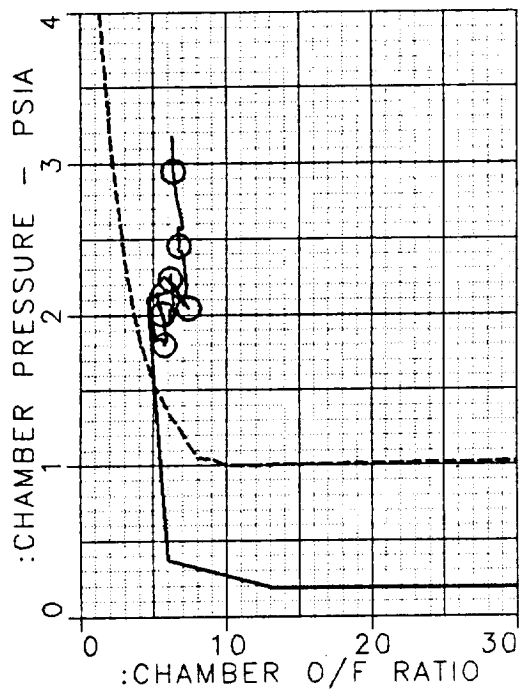
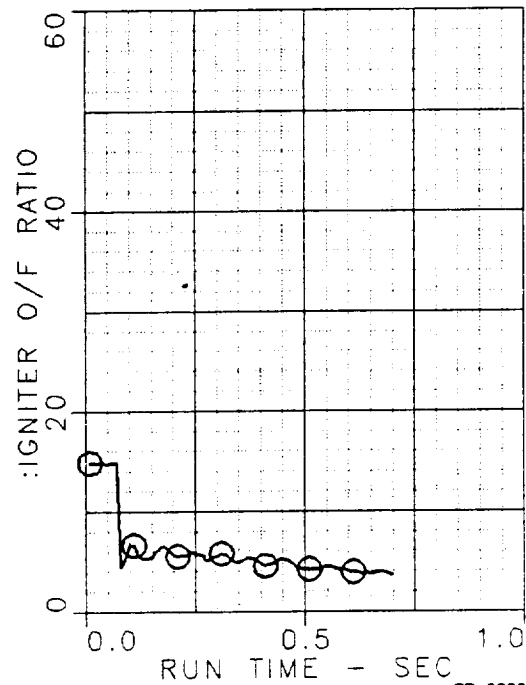
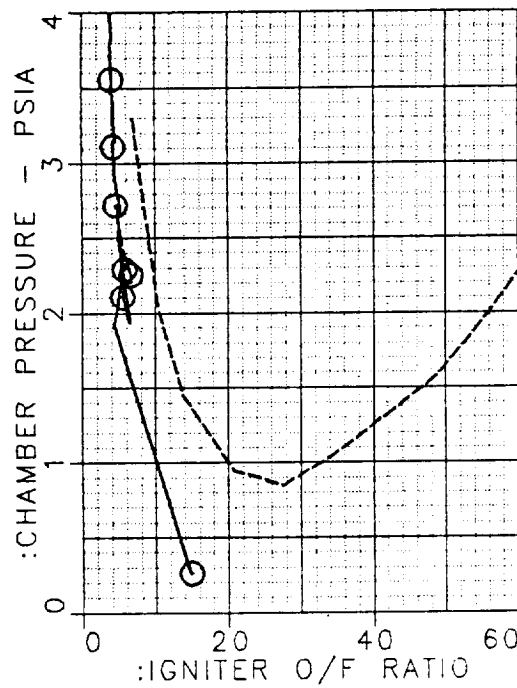
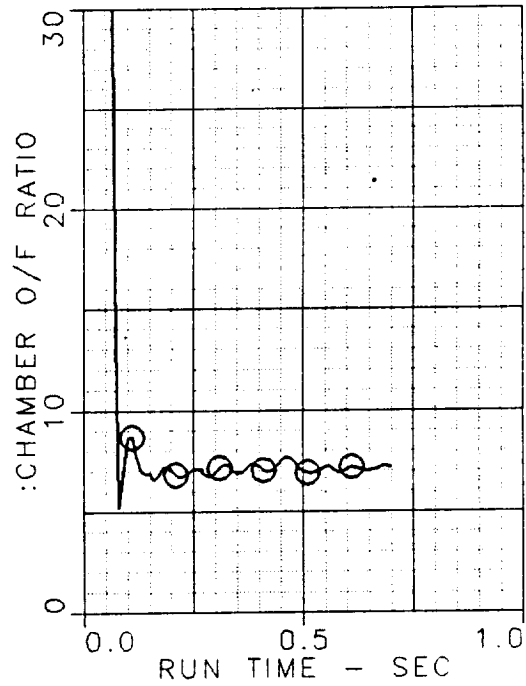
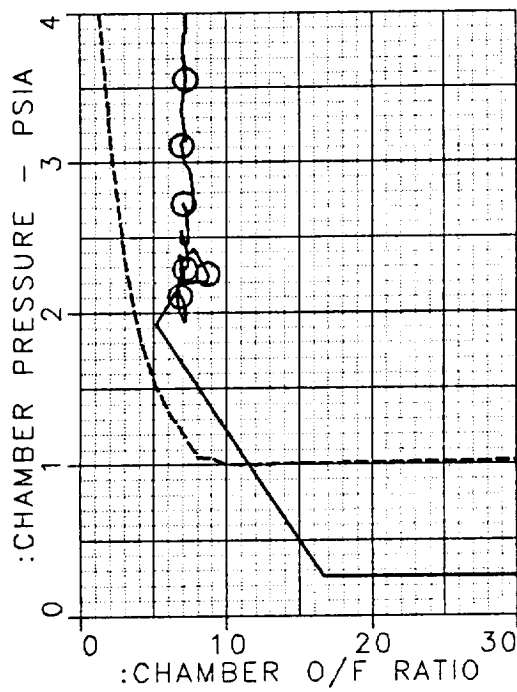


Figure A-17. Run 47.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY

- 1—○—XR103-3 RUN 51.01 START
2-----RL10 CHAMBER IGNITION BUCKET
3-----RL10 IGNITER BUCKET- MIN LEAK

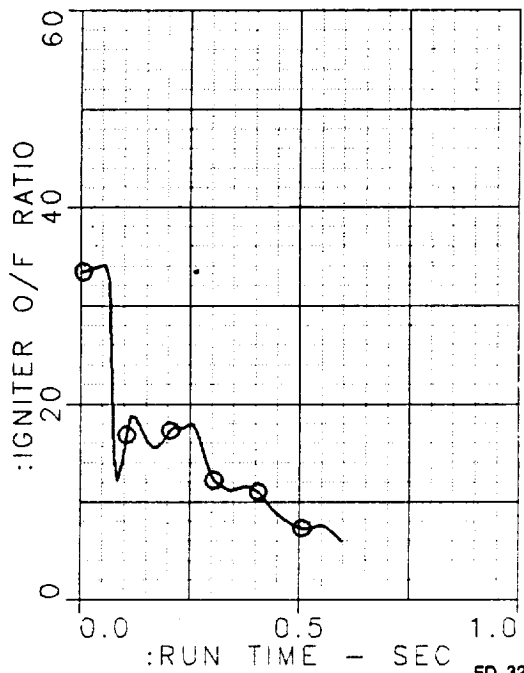
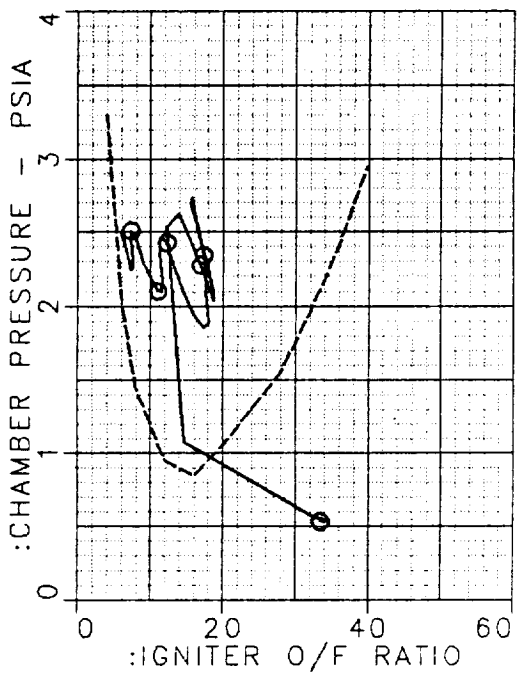
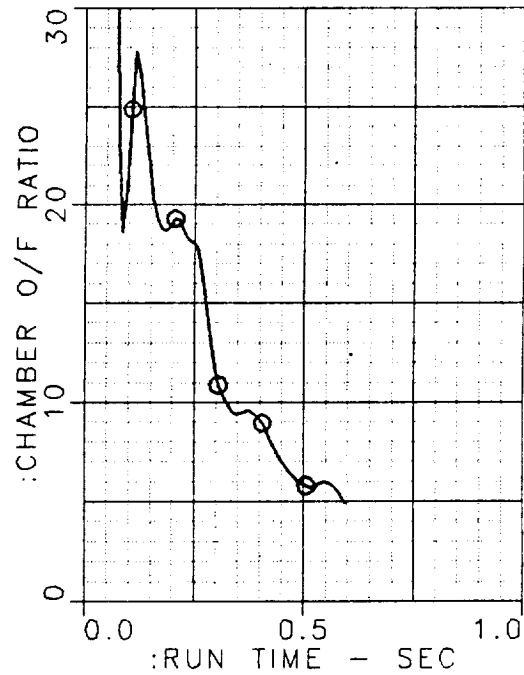
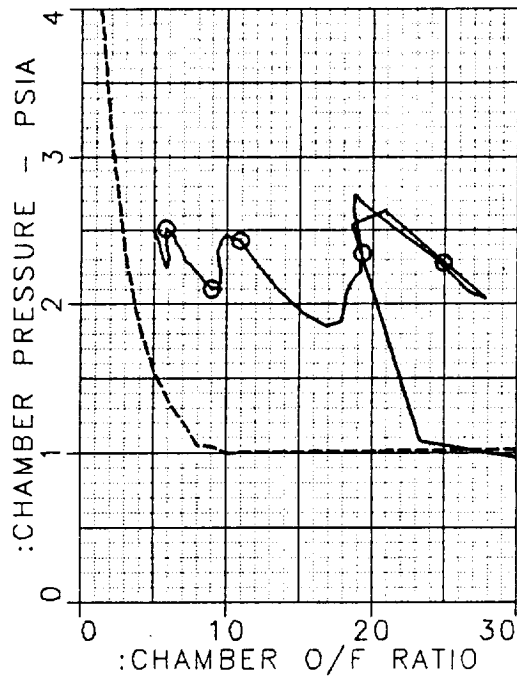


FD 320285

Figure A-18. Run 51.01

PRATT & WHITNEY, ROCKET PERFORMANCE
SHUTTLE/CENTAUR IGNITION STUDY
NOMINAL IGNITOR AREAS - NOM LEAKAGE

- 1—○—XR103-3 RUN 53.01 START FIT ST
2-----RL10 CHAMBER IGNITION BUCKET FIT ST
3-----RL10 IGNITER BUCKET- MIN LEAK FIT ST



FD 320286

Figure A-19. Run 53.01

APPENDIX B INJECTOR AND IGNITER FLOW CALCULATION METHODS

Chamber Oxidizer Flow:

The choked oxidizer flow control valve sets oxidizer flow to the chamber. O₂ flow is calculated from:

$$O_2 \text{ flow} = K \times (\text{area}) \times \sqrt{NPSP \text{ at oxidizer control valve}}$$

Chamber Fuel Flow:

The choked fuel venturi sets fuel flow:

$$H_2 \text{ flow} = K \times (FVUP) \times (\text{area}) / \sqrt{FTIT}$$

FVUP = Fuel venturi upstream pressure

FTIT = Fuel turbine inlet temperature

Note: This equation ignores the fuel surge when the main fuel valve opens and calculates flow after 0.2 second past the start signal.

Igniter Oxidizer Flow:

The igniter oxidizer holes were flow tested with nitrogen over a range of pressure ratios. Cd was back-calculated from the flow data and found to be a function of pressure ratio. A curve of Cd vs pressure ratio was generated (Figure B-1) and used to calculate flow for the test data. The calculation procedure used was:

1. Calculate oxidizer pressure ratio based on GVDP11 (see Figure B-2) and P_c.

$$PR = GVDP11/P_c$$

2. Calculate flow parameter:

$$A = (g_c / (1545/MW)) \times 2\gamma/(\gamma-1)$$

$$FP = \sqrt{\frac{A \times ((PR)^{(\gamma-1)/\gamma} - 1)}{PR^{(\gamma+1)/\gamma}}}$$

where MW = molecular weight

FP = flow parameter.

3. Use Cd curve to calculate effective flow area,

$$ACD = A_{EXIT} \times C_d$$

where ACD = effective flow area

A_{EXIT} = actual orifice area.

4. Calculate flow:

$$O_2 \text{ flow} = GVDP11 \times FP \times ACD / \sqrt{O_2 \text{ temp}}$$

Igniter Fuel Flow:

Igniter fuel flow is based on fuel injector manifold pressure (FIMP) and fuel turbine inlet temperature (FTIT). The following procedure is used:

1. Igniter supply pressure (DIMP) is calculated from FIMP using the following empirical formula:

$$DIMP = \frac{-1 + \sqrt{0.04296 \times FIMP}}{0.02148}$$

$$PR = DIMP/P_c.$$

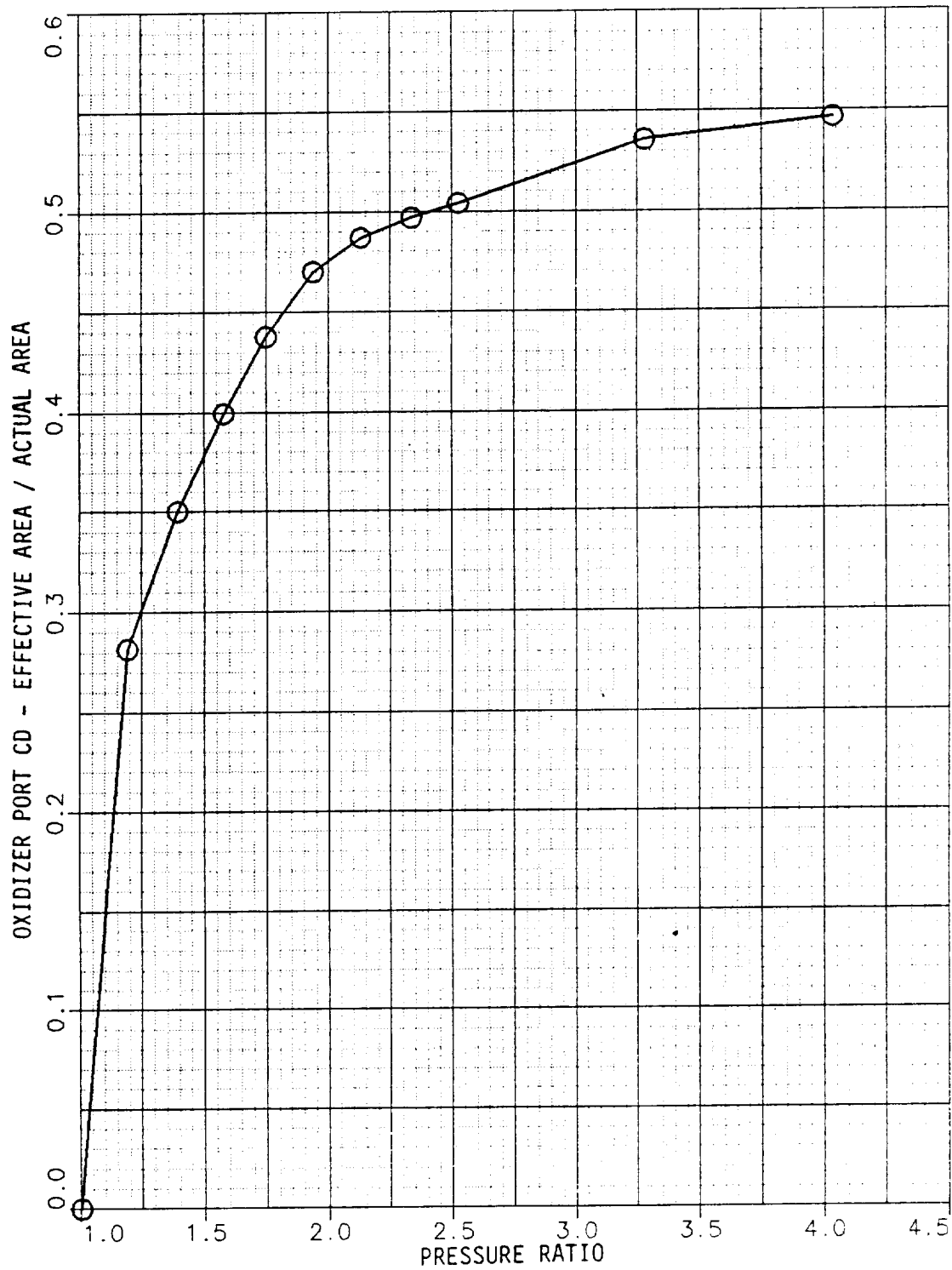
2. Flow parameter (FP) is calculated in the same manner as for the oxidizer (see step 2 above).
3. The effective flow area is the area of the fuel metering holes plus the fuel leakage area. Cd is constant for the fuel holes and is 0.69 nominally, so,

$$ACD = (\text{metering hole} + \text{leakage area}) \times Cd$$

where ACD = effective flow area.

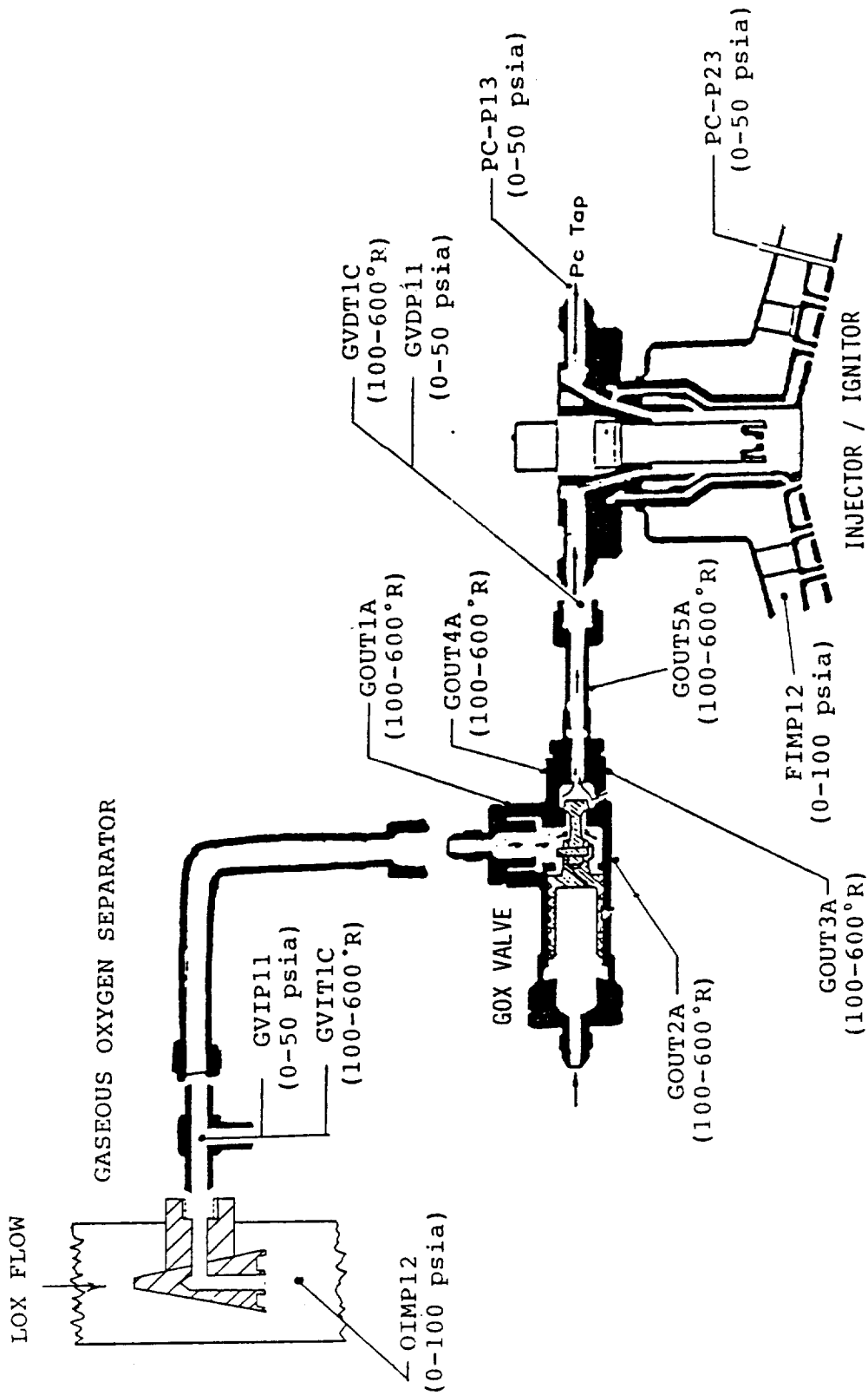
4. Calculate flow:

$$H_2 \text{ flow} = \frac{DIMP \times ACD \times FP}{\sqrt{FTIT}}$$



FD 320287

Figure B-1. Igniter CD — Oxidizer Holes



FD 320256

Figure B-2. Igniter Study — Special Instrumentation

Pratt & Whitney

FR-19556-1

APPENDIX C
SUMMARY MEMO OF ENGINE XR105-3 IGNITION TESTING

PRATT & WHITNEY
Engineering Division South

INTERNAL CORRESPONDENCE

To: R. H. Wright
From: J. W. PARK
Subject: Shuttle Centaur Configuration Ignition Investigation
Date: February 28, 1986
Copy To: J. R. Brown, R. R. Foust, C. D. Limerick,
W. C. Ring, R. B. Kaldor

CONCLUSIONS:

- o Igniter mixture ratio must be increased to assure the igniter is well within its ignition range.
- o If the chamber ignition range is correctly defined, the unlit chamber pressure must be increased. There is doubt in my mind that the predicted chamber ignition range is correctly defined at the lower chamber pressure levels, because chamber pressure levels were much higher when the ignition ranges were defined due to higher engine inlet pressures.
- o All future tests should be conducted with evacuated fuel cooldown valves during cooldown, ignition, and the start transient.

R. H. Wright

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March 12, 1986

DISCUSSION:

o Background:

Runs 35-41 of engine XR105 completed an ignition investigation to explain the reason of three previous 2nd burn no-lights. The engine and propellant conditions reflect the Shuttle Centaur configuration with a GMRV starting area of 0.05 sq-inches. First burn and relight starts and evacuated/non-evacuated fuel cooldown valves were run. Low range pressure measurements at OPDP12, OIMP12, FVUP12, FIMP12, PC-P13 were included. Unfortunately the low range PC-P13 transducer was not high response and clouds the results somewhat. Added thermocouple measurements on the inlet and exit flange of the GMRV were also included (OFCT1C and 2C located at inlet, OFCT3C and 4C located at exit). See Table-1 for run summaries.

The initiation of igniter sparking was varied between ssv-up, ssv-up plus 0.1 sec, and ssv-up plus 0.2 sec. The philosophy of delaying the spark was to verify that an ignitable condition exists after the initial surge of fuel associated with the opening of the Fuel shutoff valve (SV8). A more favorable ignition environment occurs during the initial surge.

Both the igniter and chamber must be within their ignitable region and a spark occur before ignition will occur.

o Results:

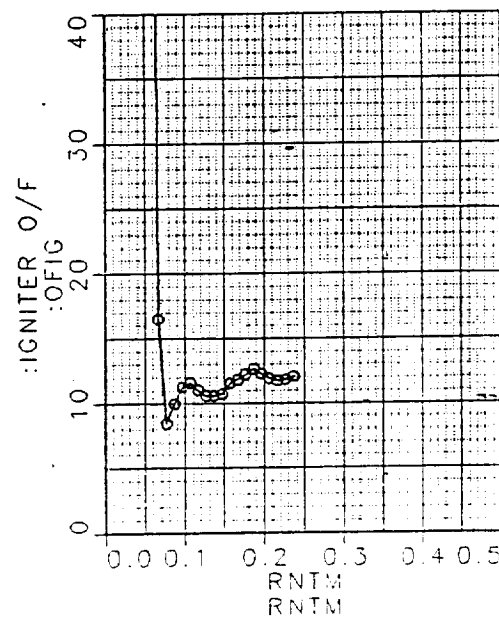
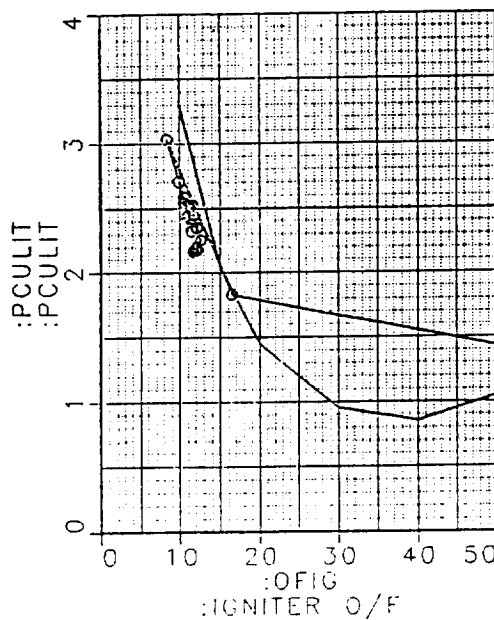
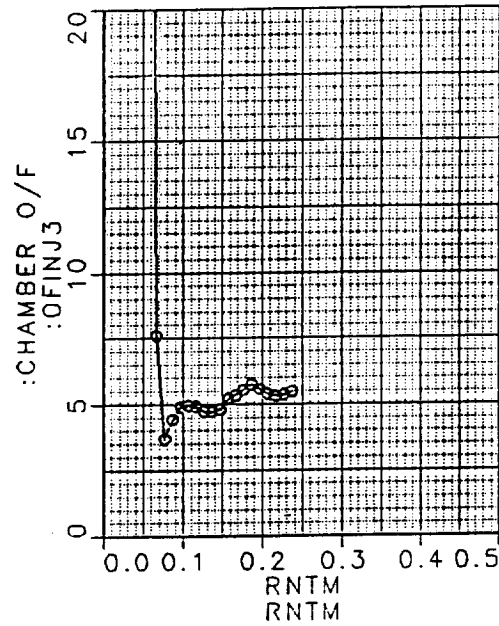
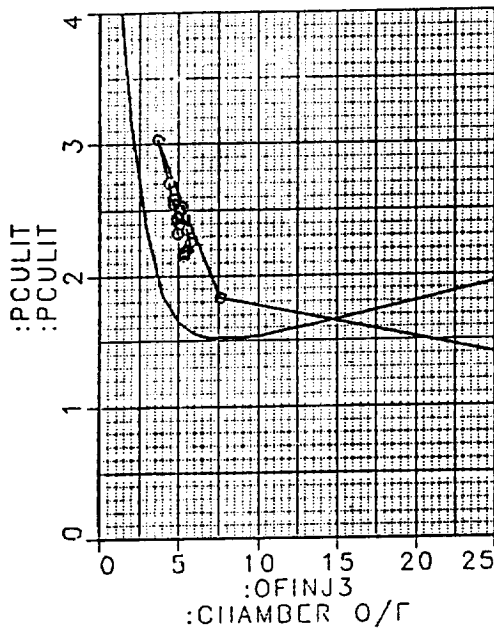
Figure-1 presents a typical run without evacuated fuel cooldown valves. Chamber conditions are shown to be well positioned within the predicted ignition range. Igniter conditions are shown to be near the oxidizer lean side of the ignition range. A calculated chamber pressure is used because of the slow response of the measured chamber pressure.

Figure-2 presents a typical run with evacuated fuel cooldown valves. Chamber mixture ratio is shown to be well positioned, but chamber pressure is below the predicted ignition range. Igniter conditions are shown to be near the oxidizer lean side of the ignition range. A calculated chamber pressure is used because of the slow response of the measured chamber pressure.

FIGURE - 1

PRATT & WHITNEY, ROCKET PERFORMANCE
FIRST BURN, VOLTAGE TO IGNITER AT 0.1 SEC
NON-EVACUATED FUEL COOLDOWN VALVES.
XR105, BUILD 3, RUN 35.01
NO VOLTAGE TO IGNITER

- 1 ○ XR105-3 RUN 35. 2 RL10 CHAMBER IGN
3 ○ RL10 IGNITER IGN



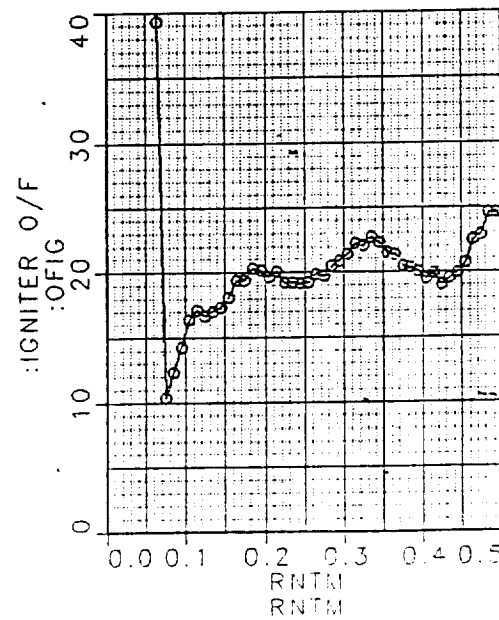
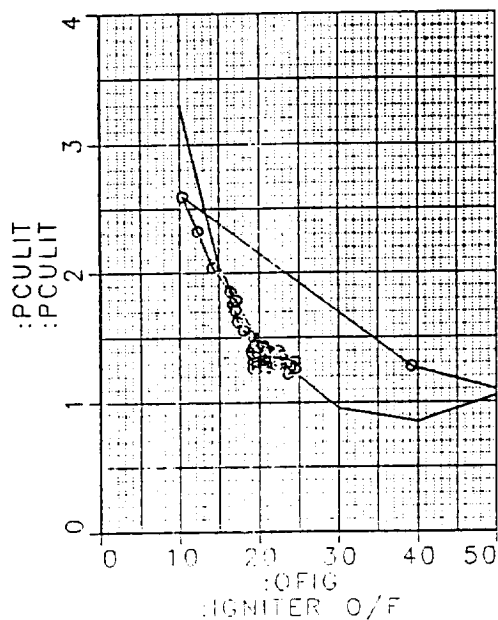
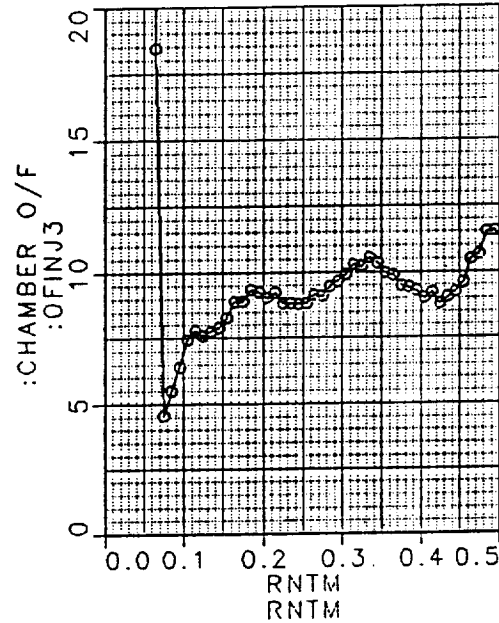
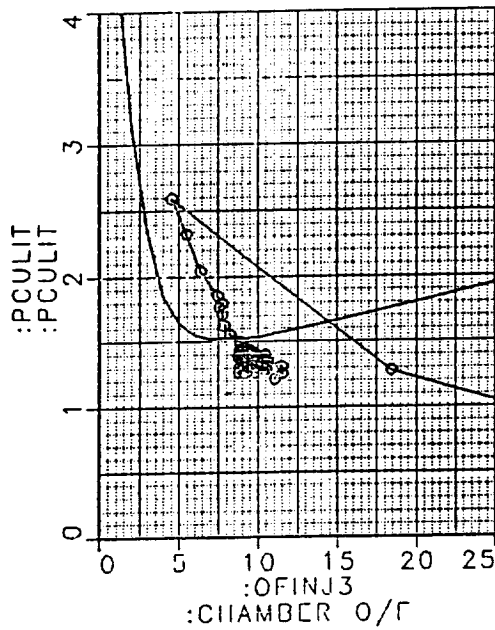
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FIGURE - 2

PRATT & WHITNEY, ROCKET PERFORMANCE
 FIRST BURN, VOLTAGE TO IGNITER AT 0.2 SEC
 EVACUATED FUEL COOLDOWN VALVES
 XR105, BUILD 3, RUN 40.01

RESULTS --- ON LIGHT

- 1 ○ XR105-3 RUN 40. 2 RL10 CHAMBER IGN
 3 RL10 IGNITER IGN



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 BROWI,VI

R. H. Wright

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March 7, 1986

TABLE - 1
RUN SUMMARY
XR105 BUILD 3 RUNS 35.01 through 41.01

RUN	TYPE	COOLDOWN	SPARK DELAY sec.	H2 C/D VALVES EVAC?	IGNITION ON WHAT SPARK?	FTIT @SSV dg-F	OIMP @SSV psia	FVUP @SSV psia	FVUP @0.2 psia
		02 / H2							
35.01	1st	250/ 36	10.00	NO	NEVER	465	5.4	23.0	18.0
36.01	1st	250/ 36	0.1	NO	1st	471	5.6	22.8	18.0
37.01	2nd	5 / 5	0.1	NO	1st	402	6.8	22.8	19.5
38.01	3rd	3 / 5	0.1	NO	NEVER	404	7.2	22.7	19.0
39.01	1st	250/ 36	0.2	NO	NEVER	488	5.5	23.0	18.0
40.01	1st	250/ 36	0.2	YES	NEVER	475	5.4	18.4	9.4
41.01	1st	250/ 36	0.0	YES	1st	475	5.5	16.2	9.0

R. H. Wright

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February 27, 1986

IGNITER AREAS FROM CCS DATA

IGNITER IDENT.		SUPPLY	PINLT	DELT-P	TEMP	FLOW	EFF AREA	AREA
P/N	S/N	02/H2	psig	psid	dg-F	scfm	sq-in	RATIO 02/H2
2120399 (CCS on 09/16/66)	KE726	02	10.1	8.0	75	7.4	0.01713	4.929
		H2	24.5	24.0	75	2.5	0.003475	
2120399 (CCS on 02/19/86)	KE726	02	35.5	8.0	72	9.0	0.01294	4.480
		02	36.0	8.0	72	8.9	0.01275	
		H2	27.0	24.0	72	2.2	0.002867	
2120399 (CCS on 02/25/86)	KE741	02	34.5	8.0	72	8.6	0.01255	4.816
		Pc Tap	33.5	4.0	72	8.6	0.01707	
		H2	27.0	24.0	72	2.0	0.002606	
2120399 (CCS on 02/25/86)	KE764	02	26.5	8.0	72	6.9	0.011236	4.484
		Pc Tap	33.5	4.6	72	8.6	0.016037	
		H2	26.5	24.0	72	1.9	0.002506	
2183710 (CCS on 02/25/86)	BMT001	02	35.0	8.0	72	8.7	0.012618	5.035
		Pc Tap	32.0	4.2	72	8.5	0.01680	
		H2	26.5	24.0	72	1.9	0.002506	
2183710 (CCS on 02/25/86)	BMT003	02	30.0	8.0	73	7.5	0.01162	3.919
		H2	27.5	24.0	73	2.3	0.002965	
2183710 (CCS on 02/25/86)	BMT003	02	31.0	8.0	72	7.9	0.01206	4.067
		Pc Tap	36.5	5.3	72	9.2	0.01558	
		H2	27.5	24.0	72	2.3	0.002965	
2183710 (CCS on 07/23/84)	BMT004	02	42.0	8.0	72	8.9	0.011933	3.663
		H2	27.0	24.0	72	2.5	0.003258	
2183710 (CCS on 07/24/84)	BMT005	02	43.0	8.0	72	8.8	0.011678	3.584
		H2	27.0	24.0	72	2.5	0.003258	
2183710 (CCS on 07/20/84)	BMT006	02	40.0	8.0	72	8.8	0.012052	2.492
		H2	37.0	24.0	72	4.6	0.004836	
2183710 (CCS on 07/18/84)	BMT007	02	37.0	8.0	72	8.2	0.011614	3.803
		H2	28.0	24.0	72	2.4	0.003054	
2183710 (CCS on 02/25/85)	BMT008	02	37.0	8.0	72	8.0	0.011331	3.952
		H2	27.0	24.0	72	2.2	0.002867	
2183710 (CCS on 03/01/85)	BMT009	02	35.0	8.0	72	7.8	0.011313	3.993
		H2	27.5	24.0	72	2.2	0.002833	

R. H. Wright

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February 27, 1966

IGNITER IDENT.		SUPPLY	PINLT	DELT-P	TEMP	FLOW	EFF AREA	AREA RATIO 02/H2
P/N	S/N							
2183710	BMT010	02	40.5	8.0	72	8.6	0.011715	3.725
(CCS on 08/05/85)		H2	28.5	24.0	72	2.5	0.003145	
2183710	BMT011	02	39.0	8.0	72	8.4	0.011631	3.853
(CCS on 09/03/85)		H2	28.5	24.0	72	2.4	0.003019	
2183710	BMT012	02	35.0	8.0	72	7.2	0.010370	3.287
(CCS on 09/04/85)		H2	27.5	24.0	72	2.5	0.003155	
2183710	BMT013	02	41.0	8.0	72	8.3	0.011246	3.842
(CCS on 08/05/85)		H2	28.0	24.0	72	2.3	0.002927	
2183710	BMT014	02	42.5	8.0	72	8.7	0.011605	3.548
(CCS on 08/01/85)		H2	28.5	24.0	72	2.6	0.003271	
2183710	BMT015	02	21.0	8.0	73	6.0	0.010724	3.820
(CCS on 01/27/86)		H2	26.0	24.0	73	2.1	0.002807	
2183710	BMT016	02	32.0	8.0	73	8.1	0.012213	4.351
(CCS on 01/27/86)		H2	26.0	24.0	73	2.1	0.002807	
2120399	BLG010	02	11.2	8.0	73	9.2	0.020570	7.413
(CCS on 12/14/82)		H2	24.5	24.0	73	2.0	0.002775	
2120399	BLG011	02	32.0	8.0	72	7.5	0.011328	4.243
(CCS on 11/16/83)		H2	26.0	24.0	72	2.0	0.002670	
2120399	BLG014	02	38.5	8.0	72	8.7	0.012113	3.718
(CCS on 11/11/83)		H2	27.0	24.0	72	2.5	0.003258	
2120399	BLG015	02	14.8	8.0	75	9.0	0.018370	6.649
(CCS on 07/26/83)		H2	24.8	24.0	75	2.0	0.002763	
2120399	BLG016	02	40.0	8.0	72	8.7	0.011915	4.206
(CCS on 07/02/84)		H2	27.5	24.0	72	2.2	0.002833	
2120399	BLG018	02	40.5	8.0	72	8.8	0.011987	3.878
(CCS on 07/02/84)		H2	27.5	24.0	72	2.4	0.003091	
2120399	AGM038	02	30.0	8.0	75	8.0	0.011484	3.380
(CCS on 07/12/78)		H2	27.0	24.0	75	2.6	0.003398	

R. H. Wright

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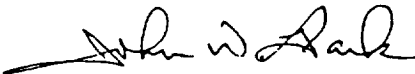
February 28, 1986

1966 CCS DOES NOT AGREE WITH 1986 CCS OF IGNITER KE726

The calculated area of the oxygen side of the igniter was 0.01713 in 1966 and is 0.0128 in 1986. Likewise, the calculated area of the fuel side of the igniter was 0.003475 in 1966 and is 0.00286 in 1986. (25% smaller on the oxygen side and 18% smaller on the fuel side) The severe change in pressures required to flow the igniter is probably caused by a change in the flow meter. However, this should not change the calculated area. Assuming that the pc tap may have been mistaken for the oxygen tap in 1966, the Pc Tap was CCS'ed on four igniters (see Pc Tap line under SUPPLY). Notice that the calculated area flowing through the Pc Tap is in good agreement with that calculated for the oxygen side of the igniter in 1966.

A real problem caused by this unknown shift in calculated areas for an identical igniter is the ignition limits defined in the 1966 era using igniter areas defined in that day do not apply today using a different set of areas. Fortunately, the ratio of O₂/H₂ areas is only different by 10%.

The other problem is how accurate is a calibration method which yields this kind of discrepancy? A recommended calibration procedure is to set a fixed upstream pressure and use a flow measuring device which will pass the flow with an pressure sufficiently low to assure choking of the igniter passages (igniter downstream pressure in psia must be less than 1/3 the igniter inlet pressure in psia). The igniter area calculation requires an inlet pressure and the flow parameter. The flow parameter is a function of the restricting area's pressure ratio, but is limited to a choked value. By assuring the passages are choked, the choked flow parameter can be used and downstream pressure is not needed. The igniter passages are choked during the ignition portion of the transient and a choked calibration should yield a more accurate flow calculation.



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Systems Performance - Rockets

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